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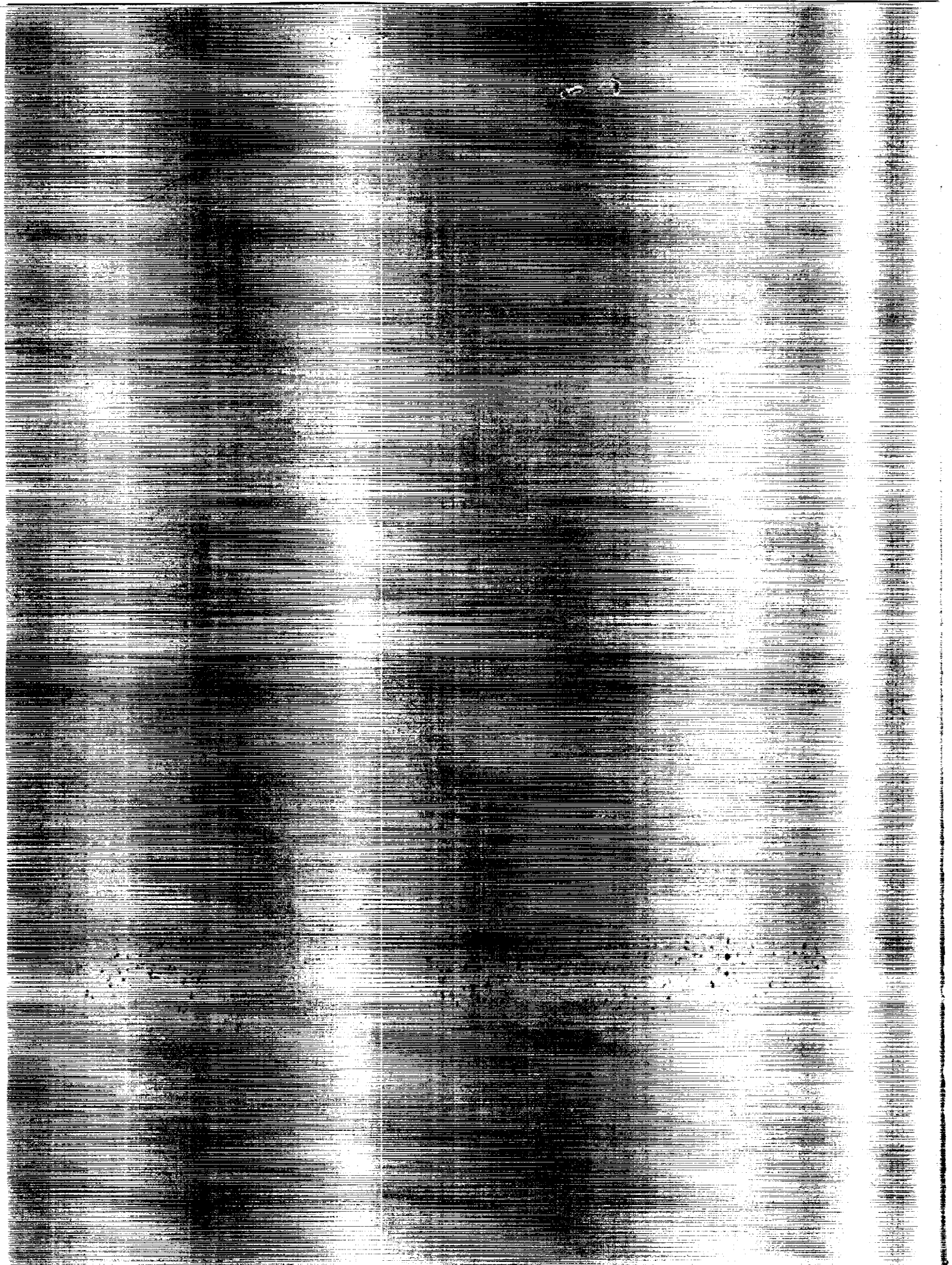
LIFE SCIENCES DIVISION

STRATEGIC IMPLEMENTATION PLAN



APRIL 1989

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LIFE SCIENCES DIVISION

STRATEGIC IMPLEMENTATION PLAN

APRIL 1989

Life Sciences Division
Office of Space Science and Applications
National Aeronautics and Space Administration
Washington, D.C.

FOREWORD

Since 1970, the direction of space life sciences has evolved from operational medical support and enabling human survival in space to seeking an understanding of the causative mechanisms underlying space adaptation, predicting related health-threatening issues, and developing more effective procedures and countermeasures. In addition, the program has begun to emphasize basic sciences in the areas of fundamental biology and planetary ecology. By combining basic and applied scientific research, it is now possible to acquire the biomedical knowledge and technological capability to enable humans and other species to venture safely into near-Earth space and beyond. At the same time, the program addresses some of the most fundamental questions of science and mankind: How has gravity shaped the development of life, indeed our existence? What is the origin of life itself? How is life interacting with and changing planet Earth? Does life exist elsewhere in the universe?


Today, the Life Sciences Program covers a truly interdisciplinary field, both advancing scientific and technical knowledge and optimizing life support for human space flight, exploration and safe return to Earth.

Activities in support of these two major program thrusts include: a biomedical and advanced technology development program aimed at producing requirements, procedures, and subsystems for health maintenance, medical operations, and extravehicular activity (EVA); closed loop life support systems research and development directly supporting manned space missions; and, a basic bioscience program that includes space and global biology and exobiology. Each program makes a unique contribution to the biological sciences, and no program area is considered secondary in the integrated strategy. The sequence, pace, and priorities for implementation in each of the three areas are dependent upon the overall goals of the National Space Policy and the opportunities for contributing to these goals.

This document delineates the strategic constraints and provides a programmatic reference for the activities of the Life Sciences Division, NASA Office of Space Science and Applications (OSSA). The Plan takes into consideration the requirements and recommendations formulated by different NASA offices and Life Sciences advisory groups.

The Plan includes currently approved programs and projects. It also describes proposed initiatives and program enhancements for future years, leading to programmatic and budgetary review and approval. These planned activities are included to indicate the direction of the programs and to present current and future activity in an appropriate visionary context.

This Plan is controlled by the Life Sciences Division and will be updated annually, based primarily upon overall NASA programmatic priorities and decisions.



Arnould E. Nicogossian, M.D.
Director, Life Sciences Division

LIFE SCIENCES GOALS

AND

LIFE SCIENCES OBJECTIVES

To ensure the health, well-being, and performance of humans in space

Understand the physiological, sociological, and psychological implications of human space flight and return to a gravity field.

Determine and develop medical and life support capabilities to enable human expansion beyond the Earth and into the solar system in conjunction with mission program offices.

Manage and ensure effective implementation of all space operational medicine activities in NASA.

To develop an understanding of the role of gravity on living systems in space

Determine the combined effects of microgravity and other environmental stresses on biological systems.

Understand the effects of gravity on the life cycles of animals and plants.

To expand our understanding of the origin, evolution, and distribution of life in the universe

Understand the origin, evolution, and distribution of life in the universe and search for evidence of extraterrestrial life.

Investigate how biological and planetary processes interact.

To promote the application of life sciences research to improve the quality of life on Earth

Support focused activities to identify and pursue such applications.

LIFE SCIENCES DIVISION STRATEGIC IMPLEMENTATION PLAN

TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	i
LIFE SCIENCES GOALS AND OBJECTIVES	ii
TABLE OF CONTENTS	iii
TABLE OF FIGURES	iv
 I. GOALS AND OBJECTIVES	 1
A. National Space Policy	1
B. NASA Goals and Long-Range Planning	1
C. OSSA Strategic Planning	1
D. Life Sciences Strategic Planning and Goals	2
 II. LIFE SCIENCES PROGRAM AND PLANNED INITIATIVES	 5
A. Integrated Discipline Approach	5
B. Operational Medicine	5
C. Biomedical Research	7
D. Space Biology	12
E. Exobiology	13
F. Biospheric Research	15
G. Controlled Ecological Life Support System	17
H. Flight Programs and Advanced Technology Development	18
I. Summary of Current and Planned Initiatives	19
J. Life Sciences Educational Program	19
K. Earth Benefits from Space Life Sciences	21
 III. PROGRAM IMPLEMENTATION	 21
A. Major Programmatic Constraints	21
B. Program Priorities and Decision Process	21
C. NASA Infrastructure	22
D. Universities	23
E. Other Federal Agencies	23
F. International Program	23
G. Access to Flight	27
 IV. ENABLING HUMAN EXPLORATION MISSIONS	 29
 V. MANAGEMENT	 32
 VI. RESOURCES	 35
 VII. REFERENCE DOCUMENTS	 39

TABLE OF FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1.	Life Sciences Evolving Strategies	3
2.	Life Sciences Programs Relationship to Two Principal Goals	6
3.	Operational Medicine Program	6
4.	Biomedical Research Program—EDO and EDCO	9
5.	Biomedical Research Program—EVA Development	9
6.	Biomedical Research Program—Environmental Monitoring	10
7.	Biomedical Research Program—Radiation	10
8.	Biomedical Research/Space Biology Programs—Bioplatforms	11
9.	Space Biology Program	13
10.	Exobiology Program	15
11.	Biospheric Research Program	16
12.	CELSS Program	18
13.	LSD Science Programs Relationship to Program Initiation—Near Term	20
14.	Life Sciences Initiatives Being Planned—Mid/Long-Term	20
15.	Life Sciences Division Involvement with STS	24
16.	Life Sciences Division Involvement with Space Station Freedom	25
17.	Life Sciences Division Involvement with Planning of Major New Exploration Missions	26
18.	Life Sciences Spacelab Activities	28
19.	Life Sciences Strategies for Evolving Requirements and Technologies	30
20.	Interlocking Relationships Among the STS, Space Station Freedom, and Major Human Exploration Missions	33
21.	Life Sciences Division Organization	34
22.	Life Sciences Division Core Program	36
23.	Relative Distribution of Science Activities (FY 1989)	37
24.	Life Sciences Portion of President's FY 1990 Budget	37
25.	Life Sciences FY 1990 Budget Information	38
26.	Life Sciences FY 1990 Budget Information	38

I. GOALS AND OBJECTIVES

The Life Sciences Program is developed within the context of the National Space Policy, NASA Goals and Long-Range Planning, Office of Space Science and Applications (OSSA) Strategic Planning, Office of Exploration (OEXP) Planning, and the recommendations of the Life Sciences Strategic Planning Study Committee. The Program is both responsive to and constrained by these policy and directional inputs. See Section VII for reference documents.

A. NATIONAL SPACE POLICY

The Presidential Directive on National Space Policy, released on February 11, 1988, states that "a fundamental objective guiding United States space activities has been, and continues to be, space leadership." Of major significance is the continuing national commitment to a permanently manned Space Station.

Civilian space program goals of relevance to space life sciences are:

- Obtain scientific, technological, and economic benefits for the general population
- Improve the quality of life on Earth through space-related activities
- Promote international cooperative activities
- Expand human presence and activity beyond Earth orbit into the solar system

It was stressed that leadership in space can only be maintained through the active development of a vital scientific research base and technology programs, and the policies endorse the pursuit of endeavors in this regard.

B. NASA GOALS AND LONG-RANGE PLANNING

NASA's vision is to be at the forefront of advancements in aeronautics, space science, and exploration. To set a course into the 21st century and bring this vision to reality, NASA will pursue major goals that represent its aspirations in aviation and space. These goals are:

1. Advance scientific knowledge of the planet Earth, the solar system, and the universe beyond;
2. Expand human presence beyond the Earth into the solar system; and,
3. Enhance aeronautics research and technology development to strengthen U.S. leadership in civil and military aviation.

Successful pursuit of these major goals requires commitment to the following supporting goals:

1. Operate an effective and efficient space transportation system and develop advanced space transportation capabilities;
2. Establish the permanently occupied Space Station Freedom in low-Earth orbit during the 1990's for research, technology development, and operations; and
3. Expand space research and technology development to enable future civil mission options, to serve all national space sectors, and to promote civil space leadership.

As NASA pursues these goals, it will:

1. Promote application of aerospace technologies to improve the quality of life on Earth and extend U.S. commercial enterprise beyond Earth;
2. Conduct cooperative activities with other countries, consistent with national space goals; and
3. Develop and employ its human resources, physical facilities, and systems in space and on Earth for effective pursuit of NASA goals.

NASA long-range planning depends upon enhancements of STS capabilities, particularly extended mission durations and productive crew time. Also pivotal in future planning is the development of the Space Station Freedom and the availability of the Life Sciences research and operational facilities.

C. OSSA STRATEGIC PLANNING

The NASA Life Sciences Program is planned and directed by the Life Sciences Division, one of the elements of the NASA Office of Space Science and Applications (OSSA). OSSA is responsible for planning, directing, executing, and evaluating that part of the overall NASA program that has as its goal the utilization of the unique characteristics of the space environment to conduct a scientific study of the universe, to solve practical problems on Earth, and to

provide the scientific foundation for expanding human presence beyond Earth into the solar system.

In abbreviated form, the OSSA overall objectives are as follows:

- Observe the universe with high sensitivity and resolution across the entire magnetic spectrum by completing the great observatories.
- Complete the detailed scientific characterization of the inner solar system and the nearer regions of the outer solar system.
- Quantitatively describe the physical behavior of the Sun, the origins of solar variability, the geospace environment, and the effects of solar processes on the Earth.
- Establish observing platforms to study Earth systems on a global scale, examine the evidence of global change, and eventually develop the capability to predict changes that might occur.
- Determine, develop, and exploit capabilities of Space Station Freedom and other space-based facilities to study the nature of physical, chemical, and biological processes in a low gravity environment and apply these studies to advance science and applications.
- Conduct and coordinate all operational medicine activities within NASA; determine human health, well-being, and performance needs and establish science and technology requirements for those needs for human flight missions.
- Develop and apply advances in communications and information systems.

To maintain the OSSA program's viability, vitality, and flexibility, a strategic planning process has been initiated, which is designed to enable appropriate contributions to the achievement of overall NASA goals. Life Sciences strategic planning is an integral component of that process.

D. LIFE SCIENCES STRATEGIC PLANNING AND GOALS

The Life Sciences Division, since its establishment, has had two principal goals:

- The assurance of the health, safety, and productivity of humans in space
- The acquisition of fundamental scientific knowledge concerning space life sciences

These two goals are interactive and have been carefully balanced. The first is mandatory in the support of overall Agency human exploration goals, while the second is both supportive of the first goal and an inherent part of NASA's strategy for a balanced program in the space sciences.

Since the completion of the Skylab Program in 1974, the National Academy of Sciences and the NASA Advisory Council (NAC) were commissioned by NASA to develop science and program strategies for the different elements of space life sciences. (Several of these advisory reports are listed in Section VII.) The most recent activity and the most encompassing, concluded in 1988, was the report entitled, *Exploring the Living Universe: A Strategy for the Space Life Sciences*, conducted under the auspices of NAC. The four overarching recommendations of this Life Sciences Strategic Planning Study Committee, chaired by Dr. Frederick Robbins, were:

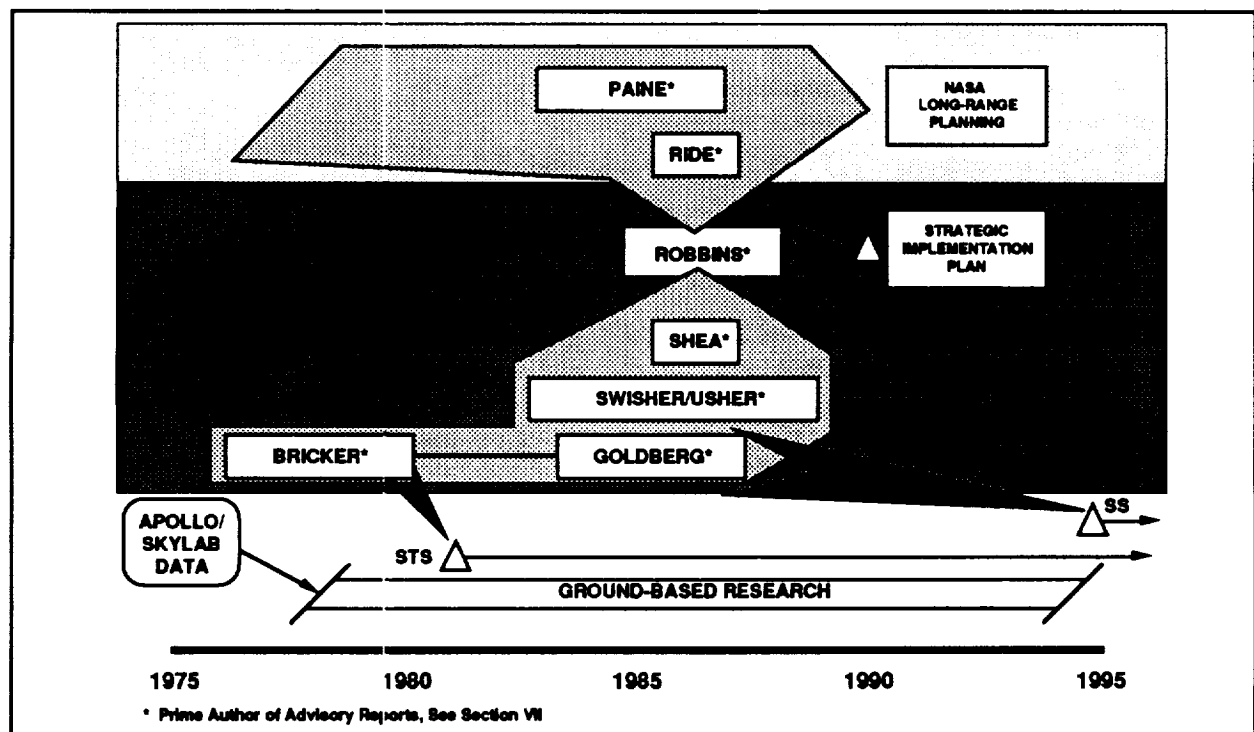
- Maintain and expand the Nation's life sciences research facilities located at NASA's field centers, universities, and industrial centers by:
 - Establishing a mechanism for attracting promising young scientists to work on NASA projects and developing additional training programs at major universities and NASA installations
 - Establishing a program of NASA-supported professorships in space life sciences at selected universities
 - Encouraging industries to develop capabilities in space life sciences through technology research and development.

- Assure timely and sustained access to space flight, thereby facilitating the conduct of critical life sciences experiments. This should be accomplished through:
 - Accumulating state-of-the-art instrumentation
 - Flying an augmented series of Spacelab missions
 - Using a series of autonomous bioplatforms to study radiation and variable-gravity effects
 - Dedicating suitable facilities on the Phase 1 Space Station for life sciences research
 - Conducting a major augmentation of life sciences capabilities during the early Post-Phase 1 Space Station.
- Synergize the presently independent research activities of national and international organizations through the development of cooperative programs in the life sciences at NASA and university laboratories.
- Complete and consolidate the unique national data base consisting of basic life sciences information and the results of biomedical studies of astronauts conducted on a longitudinal basis. This data base should be expanded to incorporate information obtained by other spacefaring nations and be available to all participating partners.

These recommendations were generated in the time frame of NASA's planning for Space Station Freedom and consideration of follow-on missions as identified by the Paine and Ride Reports. The Robbins Committee Report provided a scientific community review of research needs and is consistent with and expanded upon the previous reports (see Figure 1); it contains 250 recommendations covering all life sciences disciplines and programs and incorporates recommendations from the previous reports. The Robbins Committee Report constitutes the basis for this Plan and provides scientific justification for planned Life Sciences efforts.

The Life Sciences strategy is balanced across many science disciplines, and is based upon operational medicine experience and science continuity. The scientific disciplines are founded on periodic critical

FIGURE 1
LIFE SCIENCES EVOLVING STRATEGIES



reviews and analyses by the national and international scientific community, and exploit the capabilities made available through the established infrastructure. Well-planned integrated ground and flight research, development, and medical operations programs are essential to the success of the Life Sciences Program.

It is critical that a scientific basis exists for each step as we proceed in planning our future missions. Critical knowledge in science and operations is needed on a schedule compatible with long-range planning options. It will be necessary to pursue focused programs of scientific investigations and technology development to meet these needs. Throughout this evolving period, the pursuit of basic scientific knowledge will be balanced with the need for information to enable major exploration missions. Maintenance of this balance will receive continuing management attention.

Based on the extensive advisory committee analysis and recommended strategies, the Life Sciences Division has established the following programmatic goals and supporting objectives:

GOAL: To ensure the health, well-being, and performance of humans in space

- Understand the physiological, sociological, and psychological implications of human space flight and return to a gravity field.
- Determine and develop medical and life support capabilities to enable human expansion beyond the Earth and into the solar system, in conjunction with mission program offices.
- Manage and ensure effective implementation of all space operational medicine activities in NASA.

GOAL: To develop an understanding of the role of gravity on living systems in space

- Determine the combined effects of microgravity and other environmental stresses on biological systems.
- Understand the effects of gravity on the life cycles of animals and plants.

GOAL: To expand our understanding of the origin, evolution, and distribution of life in the universe

- Understand the origin, evolution, and distribution of life in the universe and search for evidence of extraterrestrial life.
- Investigate how biological and planetary processes interact.

GOAL: To promote the application of life sciences research to improve the quality of life on Earth.

- Support focused activities to identify and pursue such applications.

II. LIFE SCIENCES PROGRAM AND PLANNED INITIATIVES

A. INTEGRATED DISCIPLINE APPROACH

The NASA Life Sciences Program is structured into the following seven major program elements:

- Operational Medicine
- Biomedical Research
- Space Biology
- Exobiology
- Biospheric Research
- Controlled Ecological Life Support System (CELSS)
- Flight Programs and Advanced Technology Development

The scope of each of these program elements is presented in this Section. Figure 2 illustrates the overlapping relationships among the major Life Sciences programs. These relationships are identified in the following descriptions of the major program elements.

B. OPERATIONAL MEDICINE

The purpose of the Life Sciences Division's Operational Medicine Program is to ensure crew health, safety, and performance. A unique and strong preventative and clinical medicine organization in aviation and space operations is in place to support this function. This program encompasses: the development, updating, and implementation of crew medical selection and retention standards; implementation of clinical medicine programs for each manned flight mission; certification of crews for space flight duties and maintaining a health stabilization program prior to flight; and, conduct of longitudinal studies of active and retired astronauts. Activities include preflight, postflight and annual medical examinations of crewmembers, inflight health monitoring, emergency medical support, and development of flight rules and procedures. An environmental health monitoring and intervention program addresses spacecraft toxicology, barophysiology, vibroacoustics, and radiation dosimetry. Support is provided to the Office of Space Flight with respect to crew equipment development and testing (including

life support systems) and escape systems development. The Operational Medicine Program provides requirements to the biomedical program for research and development of countermeasures to mitigate changes due to space flight. It also maintains and updates the health data base to identify long-term adaptive mechanisms to single repeated exposures to space. Requirements for a Health Maintenance Facility have been developed for Space Station Freedom. In the mid 1990s, Phase A/B studies are planned to be initiated for Advanced Medical Care Facilities for future human space flight. See Figure 3 for schedules.

The following is a summary of the Life Sciences Strategic Planning Study Committee recommendations regarding Operational Medicine:

- Relevant biomedical data from astronauts should be obtained at every opportunity, both during flight (at regular intervals during long-duration missions) and longitudinally on the ground.
- Operational Medicine at NASA should work with other Agency divisions and Government health agencies that deal with issues of mutual interest, such as osteoporosis, radiation exposure, and exercise physiology.
- A prospective long-term study should be pursued investigating screening techniques, such as whole-body magnetic resonance imaging or possibly positron emission tomography, for use in crew selection for multiyear missions.
- Development of a high-pressure EVA hard suit for the Space Station should be actively pursued.
- Research into the development of countermeasures for space adaptation, including exercise, diet, and variable gravity, should continue to be pursued with vigor.
- Operational Medicine should periodically review and evaluate environmental standards for spacecraft as an iterative process to ensure crew health and safety.
- Standards for crew work, recreational, and leisure time should be established to maximize crew productivity during extended missions.

FIGURE 2
LIFE SCIENCES PROGRAMS RELATIONSHIP TO TWO PRINCIPAL GOALS

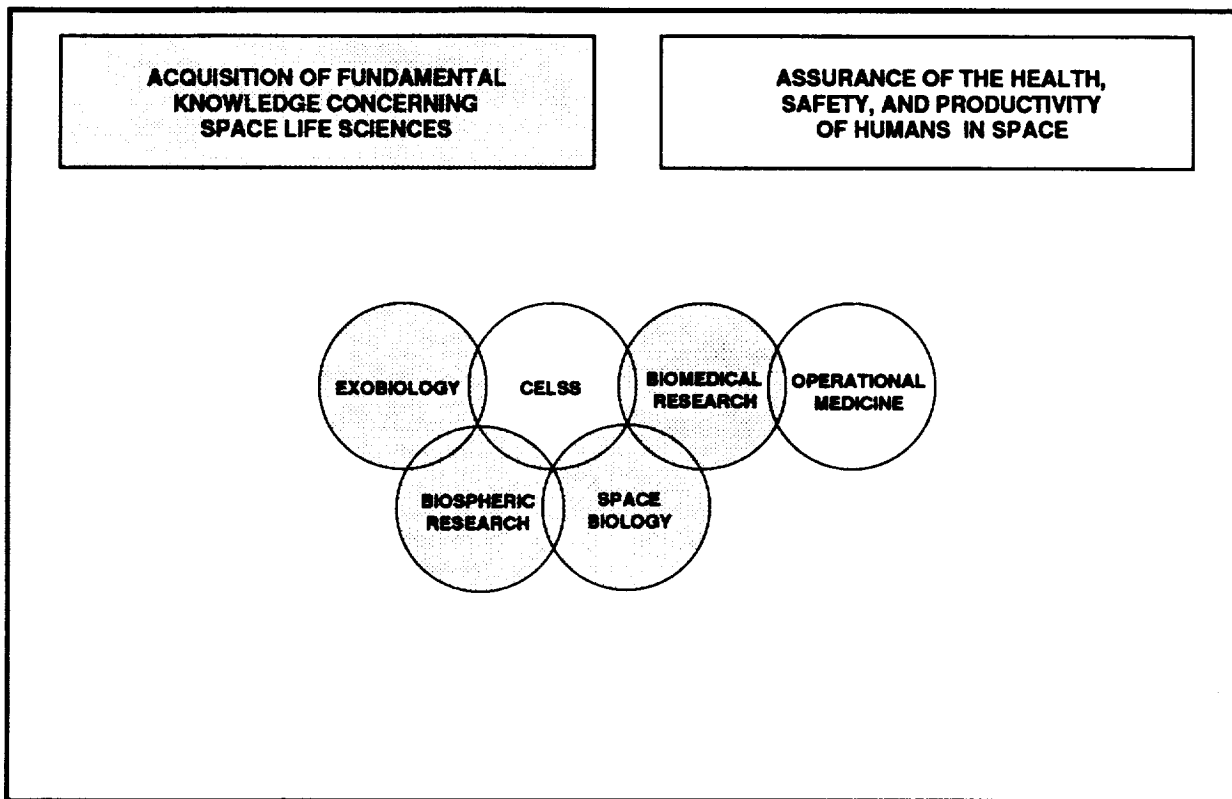
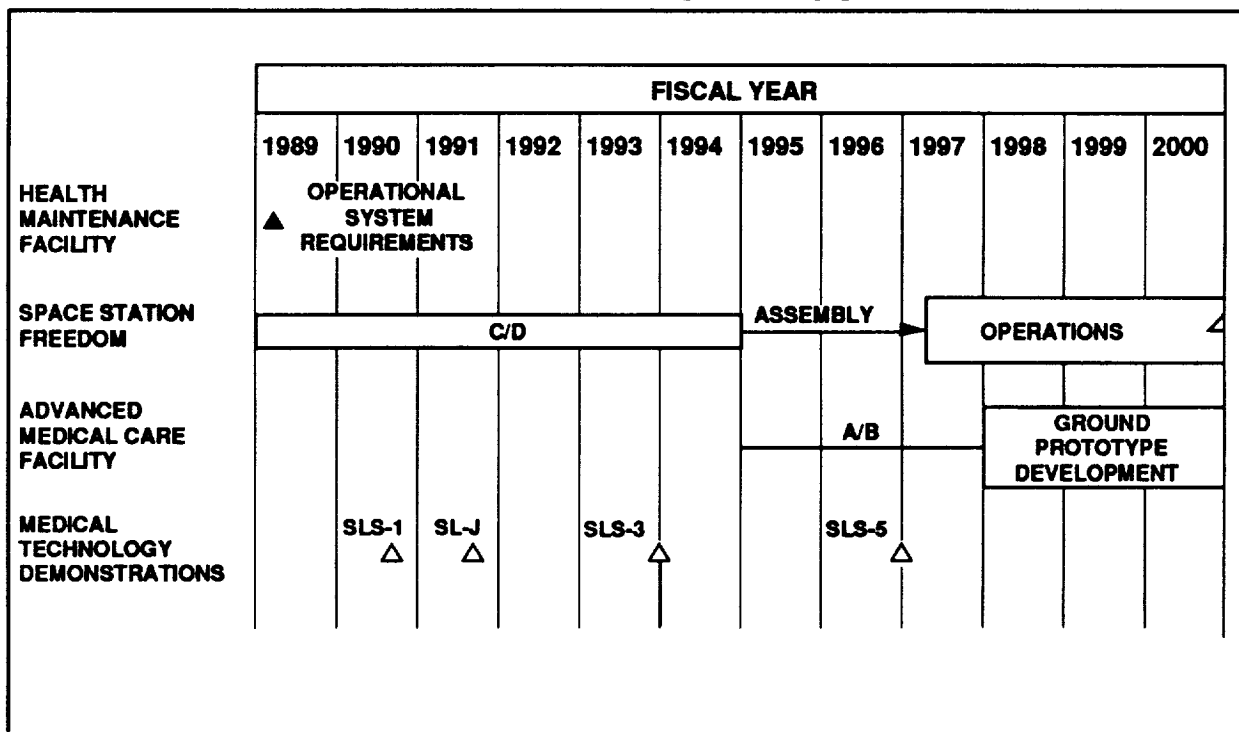


FIGURE 3
OPERATIONAL MEDICINE PROGRAM



C. BIOMEDICAL RESEARCH

The Biomedical Research Program provides the scientific base for the Operational Medicine Program and concentrates on understanding the physiological adaptive changes that occur as a result of space flight. One of the major objectives of this program is the development and testing of countermeasures to maintain the health and well-being of space crews. Our experience in space flight has demonstrated that microgravity induces adaptive responses and changes in most physiological systems. These changes, though compatible with function in weightlessness, can result in health problems, such as infections, renal calculus, or space motion sickness. In addition, adaptation to weightlessness means de-adaptation to the force of gravity in the cardiovascular, neurosensory, muscular, and skeletal systems. The environment of space flight also has an impact on the overall health and well-being of space travelers; this includes spacecraft habitability and toxicology in a confined environment, psychosociological effects of extended confinement, and cosmic radiation, which represents a particular and significant health hazard. Included is an environmental medicine research program encompassing spacecraft toxicology, microbiology, barophysiology, vibroacoustics, radiation dosimetry, and EVA requirements. The program establishes the scientific foundation for improving crew selection, medical care, training, monitoring, and for enhancing crew productivity and protection in space.

The Biomedical Research Program supports the Operational Medicine Program by providing environmental requirements and countermeasures, and medical knowledge for practice of clinical and preventative medicine.

Proposed program initiatives to implement the Biomedical strategies in 1990-1992 are described below.

- Extended Duration Orbiter Program (EDO) is a response to the requirement to extend Space Transportation System (STS) mission durations from a current maximum of 10 days up to 28 days. The extended flight times create physiological demands on the crewmembers that cannot be adequately assessed using current information. The STS differs from previous spacecraft because the crew is subjected to different hypergravity stresses before reentry and must perform reentry, landing, and egress

(including escape) operations that require proficiency and physical capabilities that were not needed before the STS era. From previous STS flights, it has become apparent that new procedures and countermeasures need to be developed to ensure the safety and success of EDO missions. During the EDO Program a database will be developed to define and understand the operational significance of flight-induced alterations in physiology. Procedures and countermeasures for optimizing crew performance for nominal and contingency entry, landing, and egress during extended missions will be developed and verified. Emphasis will be placed on maintaining orthostatic tolerance, exercise capacity, and sensorimotor function. Also, STS EDO environmental and monitoring requirements for air quality, water potability, surface contamination, radiation, waste management, and general habitability will require upgrading.

- Extended Duration Crew Operations (EDCO) is a program designed to medically qualify routine 180-day crew tours of duty on Space Station Freedom. Although some crewmembers on the Soviet Space Station Mir have stayed on orbit for periods longer than 180 days, significant inflight biomedical problems have been reported. Inflight biomedical problems experienced during long-duration space flight include muscle wasting, cardiovascular deconditioning, bone-calcium metabolism changes, and psychosocial problems. Despite extensive inflight countermeasures, crewmembers have demonstrated such problems as decreased productivity, inability to exit the Soyuz spacecraft unassisted after reentry, and recovery requiring extensive rehabilitation programs postflight.

While EDCO will provide validation of countermeasures, the Space Biology Initiative (described under Space Biology, page 11) through the study of underlying adaptive mechanisms will contribute to further refinement of countermeasures.

One objective of the EDCO Program will be to document specific factors that limit crew stay time on orbit, crew performance, postflight crew adaptation, and the frequency and number of repeat missions for individual crewmembers.

Individual and programmatic risks will be assessed and risk limits for 180-day tours of duty will be established. In addition, countermeasures to mitigate biomedical consequences of extended duration missions will be developed and tested.

- LifeSat Program, using expendable launch vehicles, will provide the capabilities to study on reusable free-flying satellites the impact of space environments on biological systems, and to control unique experimental variables to take advantage of opportunistic conditions (e.g., solar flares). An evolutionary approach will be utilized in the development of these bioplatforms which may be precursors to a human-rated variable-gravity facility. LifeSat will orbit the Earth at a higher altitude and at higher latitudes than the STS/Spacelabs. This will create an opportunity to study the effects of more intense radiation dosages. Another extremely important feature that LifeSat brings to Life Sciences research is its ability to support long-term studies of 30 to 60 days in length within its sizable payload envelope. Modules planned for LifeSat include a general biology module, a rodent module, and a botany module.

LifeSat will provide the opportunity to acquire data on relatively long-term space flight in unique environments. Over the long term, LifeSat will serve as a complement to the continuing Spacelab series of missions and the facilities on Space Station Freedom.

In addition, Phase A studies are planned to be initiated in the mid 1990s for bioplatforms capable of generating artificial gravity as follow-ons to LifeSat for long duration unmanned experimentation. These studies will be accomplished in conjunction with the Project Pathfinder in the Office of Aeronautics and Space Technology (OAST) and with the Office of Exploration Programs (OEXP). See Figures 4, 5, 6, 7, and 8 for schedules.

The following is a summary of the Life Sciences Strategic Planning Study Committee recommendations regarding Biomedical Research science:

Cardiovascular Physiology

- Adequate numbers, verification, and control of experiments must be achieved if recommendations for countermeasures are to be made according to scientific merit.

- Verification of the degree of cardiovascular deconditioning should be obtained while concomitant countermeasures are developed.
- Bed-rest studies and studies using lower body negative pressure should be continued, but they must be supplemental to inflight research.
- Instrumentation for onboard hemodynamic monitoring should be implemented according to a well-defined, long-term target.
- The role of exercise should be clearly defined in such areas as susceptibility to space deconditioning, prevention of cardiovascular deconditioning, and protection against cardiovascular dysfunction with prolonged space flight.
- Experimental studies should be conducted using humans and animal models.
- The use of a variable-gravity centrifuge in flight must be aggressively studied.

Neurophysiology and Behavioral Physiology

- The etiology of space motion sickness should be identified.
 - Changes in vestibular and proprioceptive function in microgravity should be characterized.
 - Changes in task performance should be correlated with changes in vestibular and proprioceptive functions in microgravity.
- Drug development and testing to prevent or ameliorate the untoward effects of space travel, such as space adaptation syndrome, should be made a high priority.
- Behavioral physiology research and performance should be enhanced.

Bone, Endocrine, and Muscle Physiology

- Changes in the neurohumoral responses to microgravity should be characterized and correlated with the incidence of space motion sickness or changes in task performance.

FIGURE 4
BIOMEDICAL RESEARCH PROGRAM—EDO AND EDCO

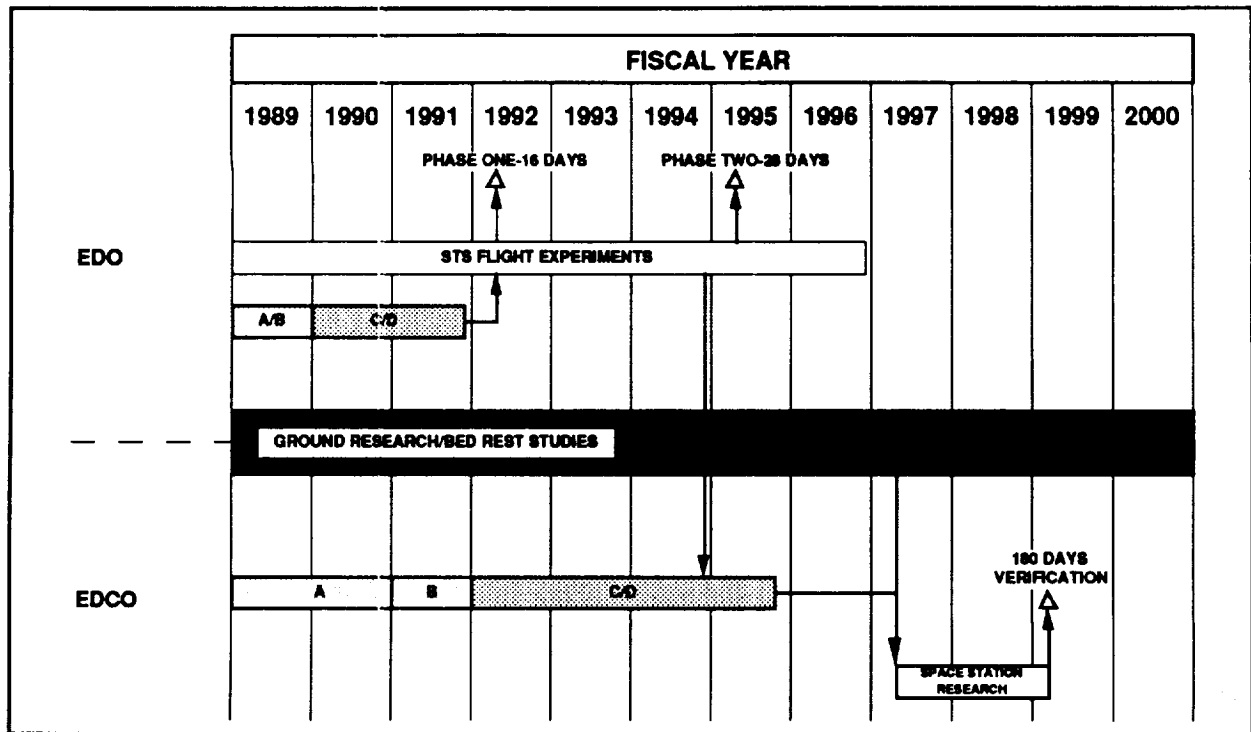


FIGURE 5
BIOMEDICAL RESEARCH PROGRAM—EVA DEVELOPMENT

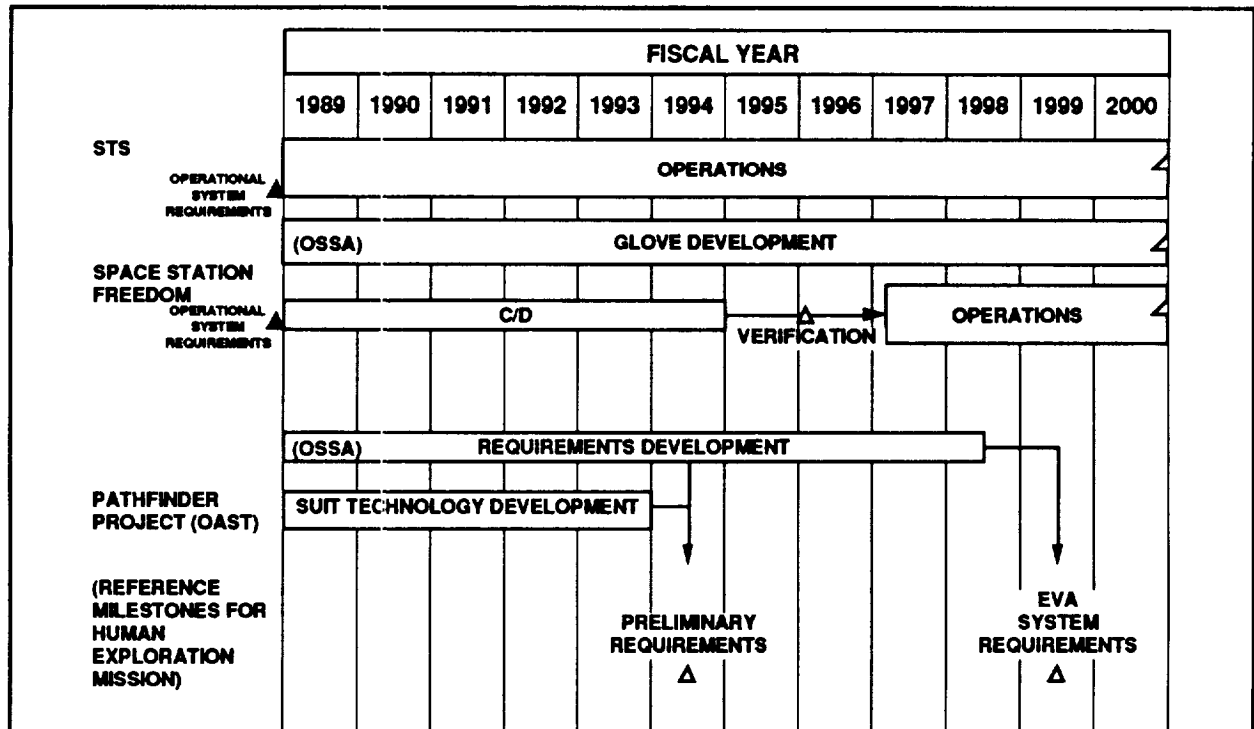


FIGURE 6
BIOMEDICAL RESEARCH PROGRAM—ENVIRONMENTAL MONITORING
(MICROBIOLOGY, TOXICOLOGY, WATER QUALITY)

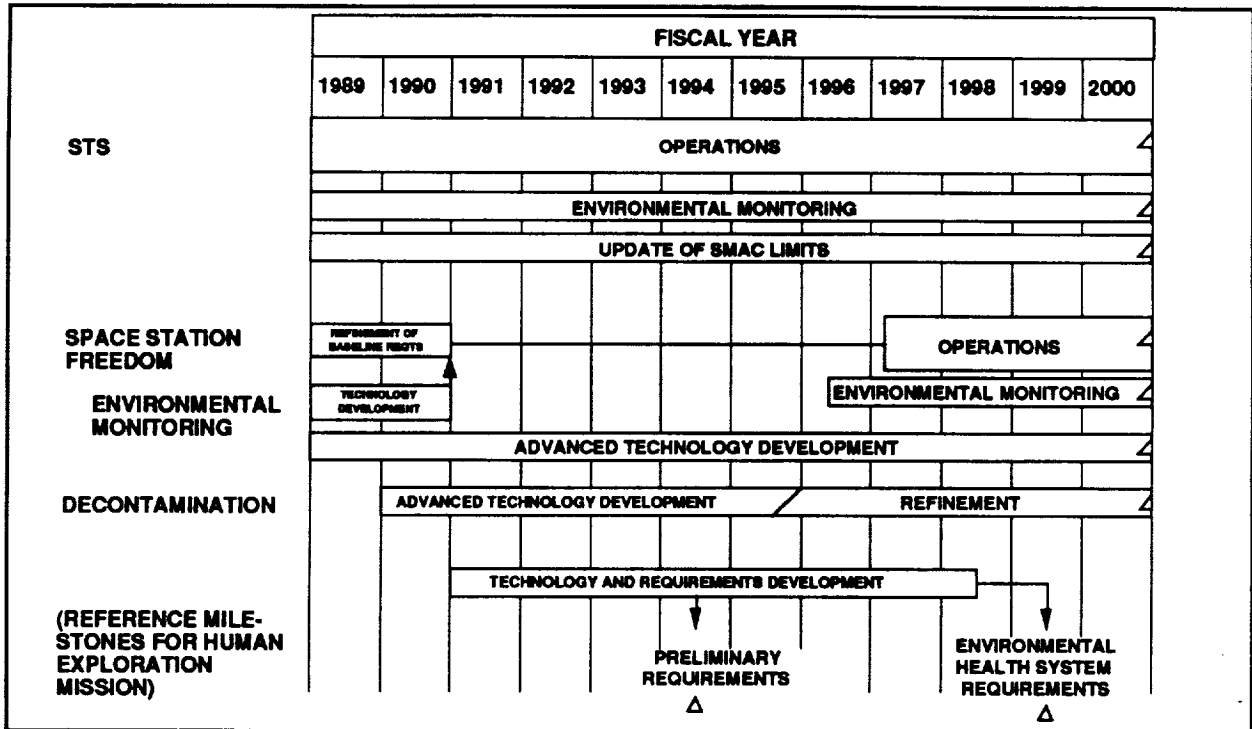


FIGURE 7
BIOMEDICAL RESEARCH PROGRAM—RADIATION

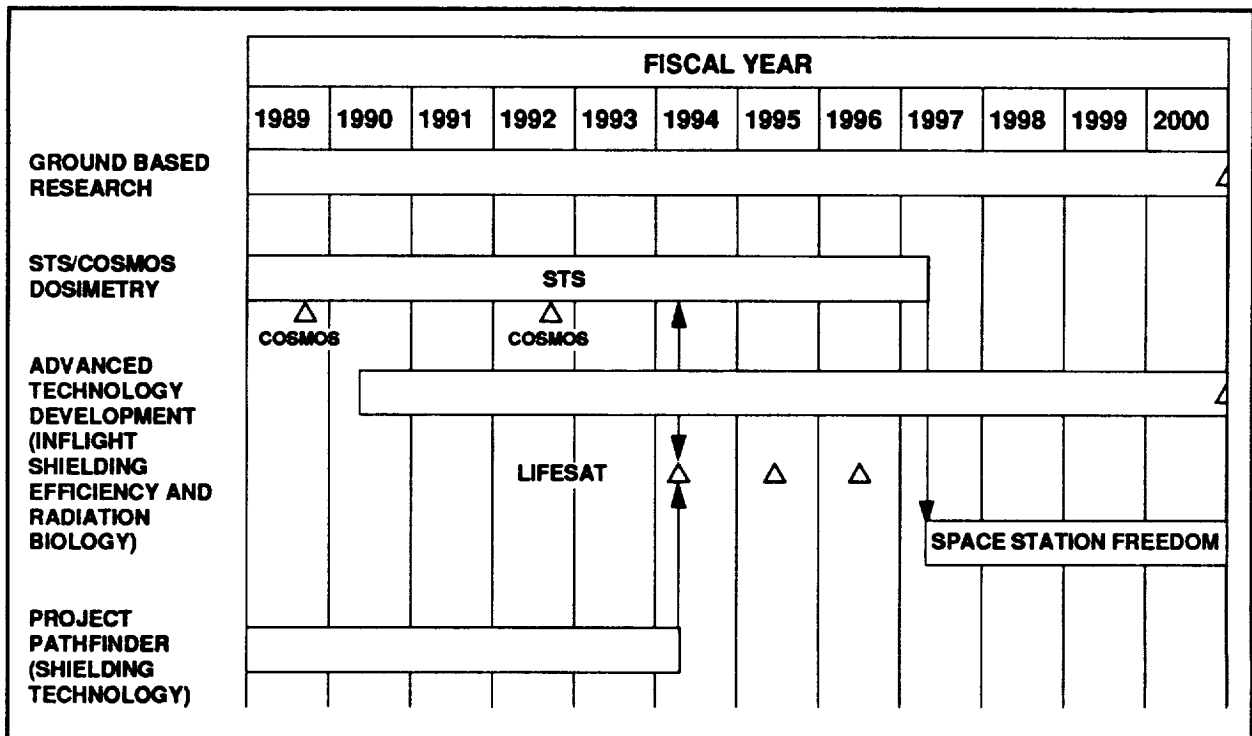
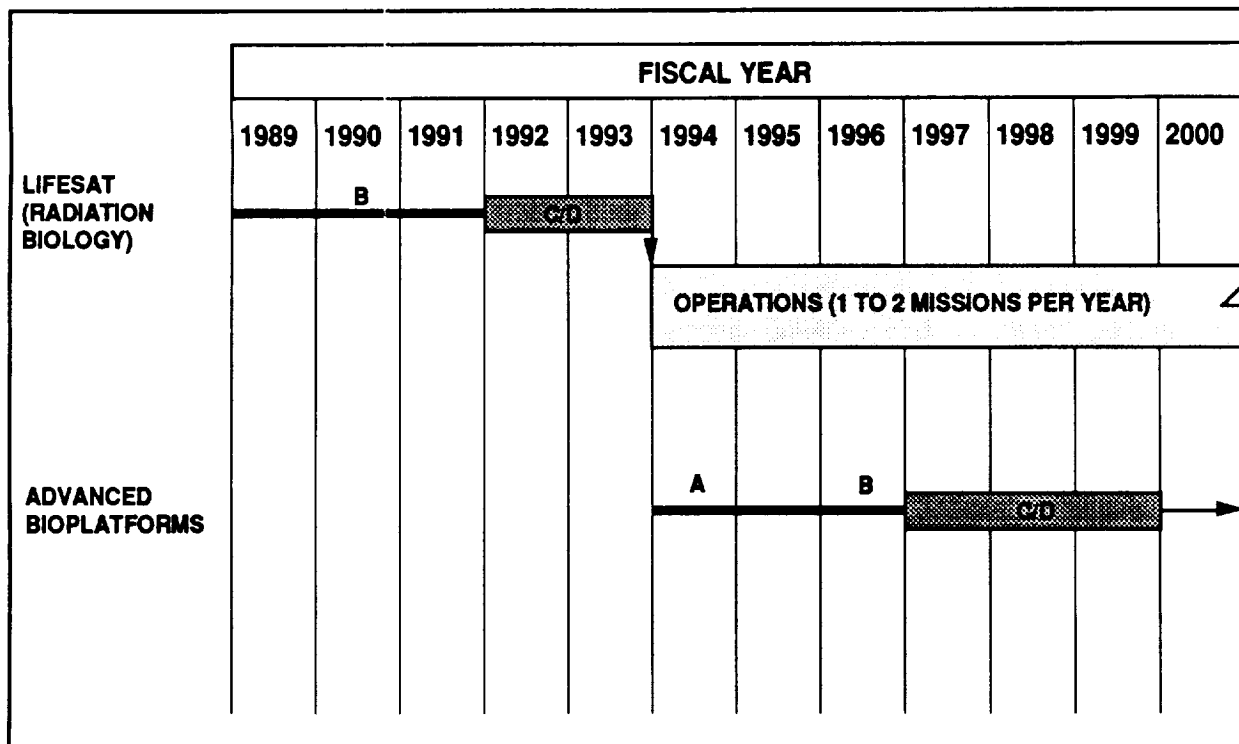


FIGURE 8
BIOMEDICAL RESEARCH/SPACE BIOLOGY PROGRAMS—BIOPLATFORMS



- The relationships between skeletal muscle atrophy and bone demineralization should be explored using bed-rest and inflight studies.
- Development of physical and/or pharmacological countermeasures should be made a high priority.

Hematology

- Erythropoietic, lymphocytic, and granulocytic changes associated with microgravity should be characterized.
- Functional changes in immunology and susceptibility to infectious diseases should be correlated with any qualitative or quantitative changes in hematopoietic cell lines.

Radiation

- NASA should vigorously pursue basic research in solar physics in order to model and predict catastrophic radiation events and to investigate short-time warning systems that will provide time for the crew to seek protection.

- NASA should vigorously pursue basic research in the radiation biology of high linear energy transfer radiation.
- NASA should direct the following efforts to work in shielding and transport research: conduct measurements of the free-space radiation environments; study the interaction of radiation with shielding materials through the development of the transport computer codes and accelerator experiments. A balanced approach in studying the free-space radiation environment, the radiation environment inside the spacecraft, and accelerator-based experiments is desirable.
- NASA needs to support basic research in instrumentation and measurement of the space radiation environment.
- NASA should make a commitment to support fundamental research on the biological effects of radiation.

D. SPACE BIOLOGY

One of the major features of the physical environment on Earth is the constant presence of gravity. The phenomenon of microgravity encountered in space provides a unique opportunity to study the role of gravity on life on Earth. Access to space provides an opportunity to manipulate gravity from one g (Earth gravity) down to almost zero, providing a broad-based gravitational research capability. The goals of the Space Biology Program are to use the unique characteristics of the space environment, particularly microgravity, as tools to advance knowledge in the biological sciences; understand the role of gravity in biological processes in plants and animals; and understand how plants and animals are affected by and adapt to the space environment. The program focuses on research to answer basic scientific questions that are of fundamental importance on Earth as well as in space. For example, understanding biomineralization and the mechanisms controlling the structural integrity of bone are important to understanding the problem of osteoporosis on Earth and bone mass loss in space.

The Space Biology Program works closely with the Biomedical Research Program with respect to physiological mechanisms of response to weightlessness.

Proposed program initiatives to implement the Space Biology strategies in 1990-1992 are described below:

- Space Biology Initiative (SBI) is a basic research flight program that allows for the development of space instrumentation to support life sciences payloads on Spacelab and Space Station Freedom. SBI involves the development of a suite of facilities supplemented by the 1.8-meter centrifuge, that will enhance scientific research as recommended by the Robbins and Goldberg Committees. SBI will enable investigations concerning how gravity is sensed and how it affects reproduction and development. Included is the study and understanding of the response mechanisms of major physiological systems (e.g., cardiovascular, pulmonary, skeletal, muscle, and neurosensory systems) to gravitational forces. To further understand these responses it will be necessary to measure biochemical, metabolic, endocrinological, and morphological interactions. Plant and developmental biologists and physiologists have speculated for centuries

about the role of gravity in fundamental processes and how the Earth's gravitational field has shaped the evolution of life on Earth. The facilities to be provided by the SBI will allow the conduct of controlled studies to address these questions in a manner that has not been possible heretofore. Extended operation Spacelab missions will continue throughout the manned and permanent manned capability phases of Space Station Freedom. SBI hardware will be used to support Spacelabs and Space Station Freedom based science as appropriate.

- 1.8-Meter Centrifuge Facility includes a variable speed centrifuge; habitats for rodents, plants, and small animals; a multi-purpose glovebox and workbench; and a specimen chamber resupply. This facility will provide the capability to vary the gravitational force on a broad range of living species, under fully controlled conditions, for extended periods. For the first time, it will be possible to expose living organisms to fractional forces up to Earth's gravity for periods long enough to understand the nature of biological responses. The physiological mechanisms responsible for gravity perception and their threshold sensitivities will be studied through controlled, replicative experiments. This facility will be available for scientific research on Spacelab as well as on Space Station Freedom. The experiments on Spacelab will focus on the short-term, transient effects of microgravity and radiation on bone, muscle, cardiovascular, neurovestibular, and other biological systems, with ultimate applications to crew health and productivity as well as to basic biology. The centrifuge will help isolate the effects of microgravity from other variables, including forces encountered during launch and reentry, solar and cosmic radiation, and environmental contamination.

Extended duration missions on Spacelab (Extended Duration Orbiter) will allow more precise analysis of the effects of microgravity. The long-duration missions possible only on Space Station Freedom will allow for expanded fundamental research employing multiple generations of animals and seed-to-seed experiments.

In addition, Phase A/B studies are planned to be initiated in the mid-1990's for a Variable Gravity Centrifuge which will be a human-rated research

facility for continuation of space experimentation begun with the 1.8-Meter Centrifuge. See Figure 9 for planned schedules.

The following is a summary of the Life Sciences Strategic Planning Study Committee recommendations regarding Space Biology:

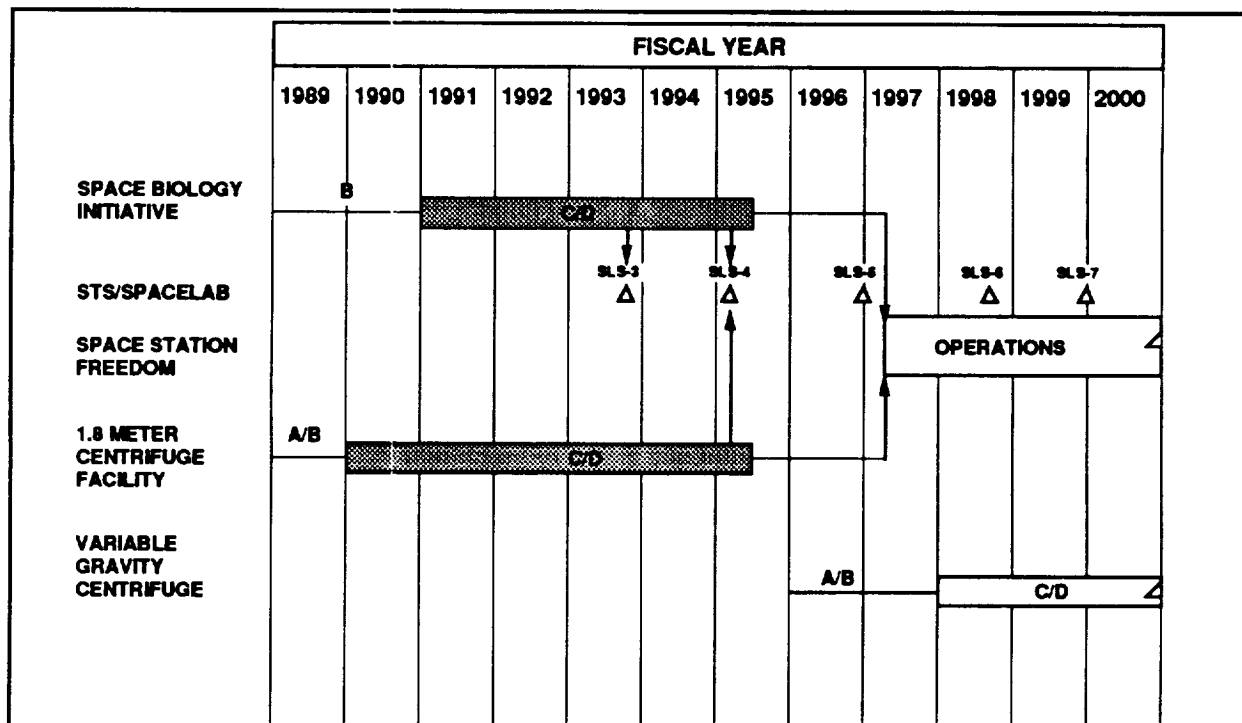
- The objectives of this research program are to:
 - Determine the role of gravity in regulating metabolic rate and products, fluid dynamics, and biorhythms.
 - Understand the effects of gravity on biological support structures and basic mechanisms of mineral and hormonal metabolism.
 - Identify the biological effects of the interaction of environmental factors, such as temperature and light, with gravity, and determine the mechanisms involved.
 - Use the space environment as a tool to determine the factors that control the structure and function of organisms.

- NASA should use a sufficient number and diversity of species to examine representative examples of gravitational perception, sensing, response, and adaptation.
- Adequate plant and animal unicellular and multicellular growth facilities must be provided that include capabilities to rear several generations under automated control. Particular emphasis should be placed on maintaining an in-orbit, multigenerational rat colony.
- Proposed investigations similar in scope to work done previously by other researchers should use standardized experimental plants and animals whenever possible.

E. EXOBIOLOGY

Knowledge gained to date suggests that life could exist elsewhere in the universe. Current research addresses the hypothesis that life is a natural consequence of the origin and evolution of stars and planets. Thus, life is part of the natural continuum of physical, chemical and biophysical processes that started with the origin of the universe itself. Research

FIGURE 9
SPACE BIOLOGY PROGRAM



is conducted in the following areas: cosmic evolution of biogenic compounds; prebiotic evolution; early evolution of life; and the evolution of advanced life. The principal goal of research in the area of the cosmic evolution of biogenic compounds is to determine the history of the biogenic elements (C, H, N, O, P, S) from their birth in stars to their incorporation into planetary bodies. Research in prebiotic evolution seeks to understand the pathways and processes leading from the origin of a planet to the origin of life. Research strategies investigate planetary and molecular processes that set the physical conditions within which chemical evolution occurred and living systems arose. The goal of research into the early evolution of life is to determine the nature of the most primitive organisms, the environment in which they evolved, and the way in which they influenced their environment. Research on the study of the evolution of advanced life seeks to determine the extrinsic factors influencing the development of advanced life and its potential distribution. This research includes an evaluation of the influence of extraterrestrial influences on the appearance and evolution of multicellular life, conducted by tracing the effects of major changes in the Earth's environment on the evolution of complex life, especially during mass extinction events, and searching for evidence of advanced life elsewhere in the galaxy. Projects conducted under this program include:

- Gas/Grain Simulation Facility (GGSF) is a joint Life Sciences Division (EB)/Solar System Exploration Division (EL) effort led by EB to develop a Space Station Freedom facility that will allow investigations of fundamental chemical and physical processes important to the cosmic origin of the biogenic elements and compounds, such as the formation, growth, nucleation, condensation, evaporation, and mutual interactions of clouds, crystals, dust grains, and other particles in a microgravity environment. (The GGSF is an element of SBI.) This facility can support selected material sciences experiments.
- Intact Cosmic Dust Collector Experiments will allow the scientific community to participate in the capture of hypervelocity interplanetary and interstellar dust particles on Space Station Freedom with a minimum amount of particle alteration. These experiments are proposed as part of the Space Station Cosmic Dust Collection Facility being developed jointly by EL/EB, led by EL.

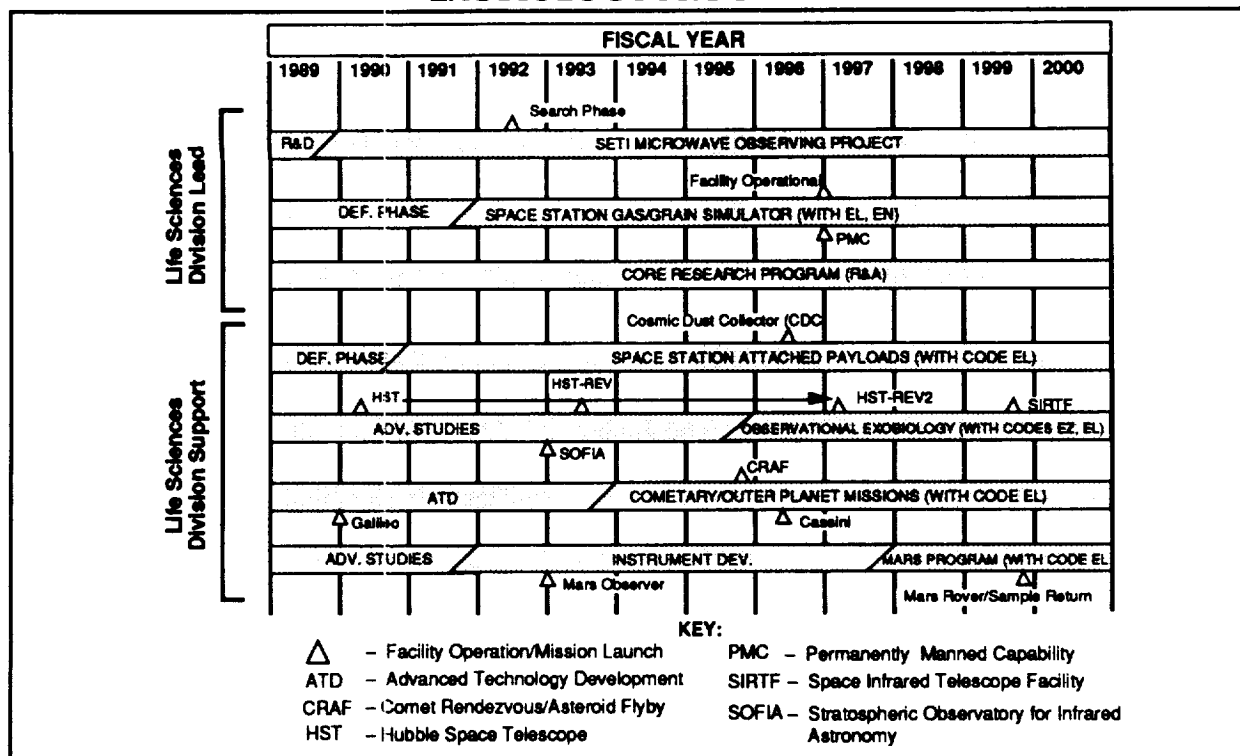
- Search for Extraterrestrial Intelligence (SETI) Microwave Observing Program (MOP) will probe our galaxy for radio signals of possible extraterrestrial intelligent origin. Using existing telescopes in NASA's world-wide Deep Space Network and additional telescopes made available by other national and foreign organizations, a targeted search will be conducted of over 800 solar-type stars within 100 light years of Earth in the 1 to 3 gigahertz frequency range, and a sky survey will be made of the entire celestial sphere for signals in the 1 to 10 gigahertz frequency range.

See Figure 10 for the overall Exobiology Program schedule.

The following is a summary of the Life Sciences Strategic Planning Study Committee recommendations regarding Exobiology science:

- NASA should pursue vigorous programs of remote observations, ground-based research, and exploration of extraterrestrial bodies.
- The Exobiology Program should continue on a broad front to support research on the prebiological evolution of functional complexity leading toward living systems, with emphasis on the following areas:
 - The organic synthesis of cellular building blocks in the context of carbon-dioxide-rich atmospheric and hydrothermal environments
 - The organic and inorganic chemical models for metabolic and self-replicating systems compatible with existing constraints on early environmental conditions
 - The nature of interactions between monomers or polymers of nucleotides and amino acids that constitute the physical-chemical basis for the genetic code.

FIGURE 10
EXO BIOLOGY PROGRAM



- In the Exobiology Program, research on contemporary organisms aimed at unraveling the evolutionary history of life should focus on the following areas:

- The abundance, physiology, and environment of the microorganisms in modern homologues of ancient microbial communities
- Models of the simplest components of the apparatus required by microorganisms to carry out the indispensable energy harvesting, metabolic, and reproductive functions of life
- The phylogeny and physiology of uncultivated organisms that inhabit hot springs, hydrothermal vents, and planktonic environments
- The nature of the common ancestor of contemporary life as characterized by molecular phylogeny.

F. BIOSPHERIC RESEARCH

Living and non-living elements of the Earth are linked by physical, chemical, and biological processes. These processes are integrated over the entire planet by the land, atmosphere, oceans, and sediments to form a system called the biosphere. The Biospheric Research Program is dedicated to understanding how biological and planetary processes interact, and how, in conjunction with the environmental effects of human activity, these processes are affecting the long-term habitability of the Earth. Research is conducted in the following areas: wetlands research; temperate forest research; tropical forest research; global monitoring and disease prediction; and global studies. Wetlands-related activities involve research to gain understanding of the role of wetlands as a major terrestrial source of many biogenic trace gases in the atmosphere. In temperate forest research, the thrust is to characterize the contribution of soil and canopy processes in temperate forests to global biogeochemical cycles and to develop mathematical models of these processes. The primary interest in tropical forest research is to understand the contributions of tropical forests to the composition

of the atmosphere and the consequences of human encroachment. The goal of global monitoring and disease prediction research using space-borne sensors and related technology is to define environmental factors, habitat, vector distribution, and ecology of insect-borne diseases. Global studies research integrates remote-sensing and ground-based data development and validation of mathematical models of regional, continental, and global biological processes in order to understand essential biogeochemical cycling aspects of the global system.

The Biospheric Research Program has developed a new research initiative, "TERRA." The goal of this initiative is to provide an understanding of global ecosystem dynamics and global change. TERRA represents the Life Sciences Division's input to NASA's overall program in Earth System Science. The planned program will exploit remote sensing technology, including Earth Probes and the Earth Observing System (Eos), to increase our understanding of the interactions between biological processes and planetary properties and how these interactions are affected by natural and human perturbations. The major objectives of TERRA are to:

- Continue and extend present studies in biogeochemical cycling.

- Support a new emphasis on biological research at the population and community level.
- Enhance support for applications of population-level studies to disease-vector populations.
- Promote development of remote sensing expertise in the ecological community.

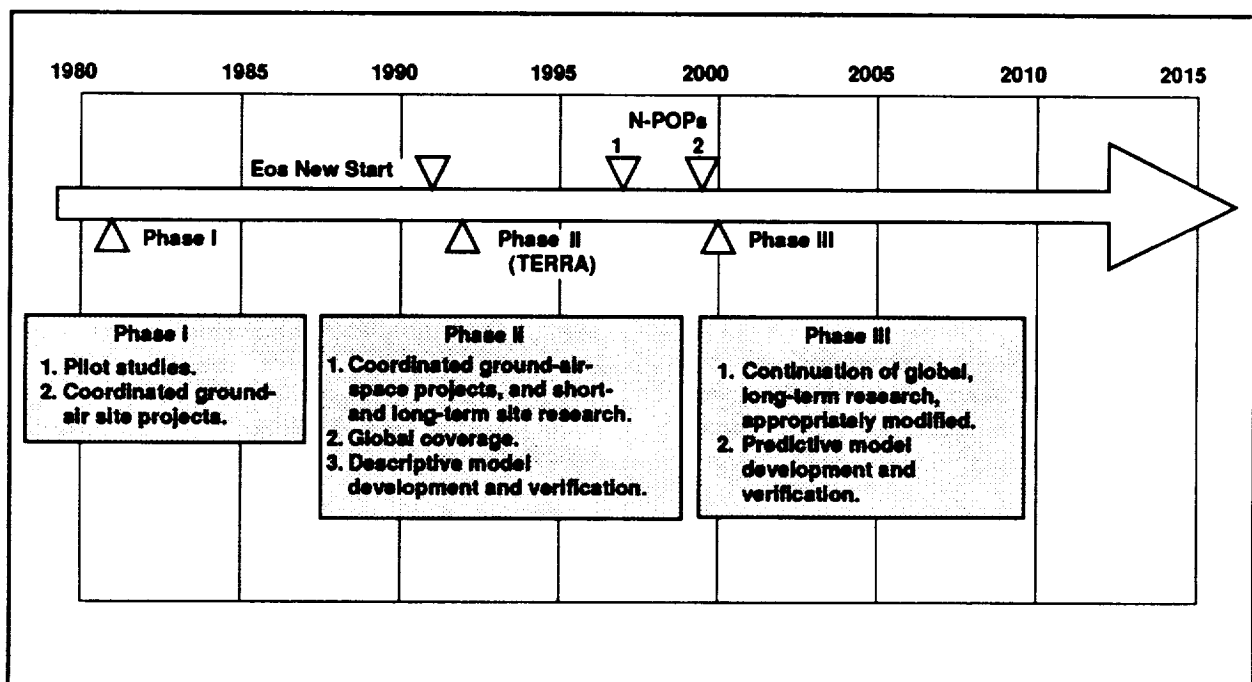
Through TERRA and associated activities, the Biospheric Research Program will implement the goals noted below in the reports "Earth System Science: A Closer View" and "Global Change in the Geosphere-Biosphere" (See Section VII, Reference Documents). See Figure 11 for schedule.

The Biospheric Research and Exobiology Programs are interrelated with respect to the evolution of biota and planetary geochemistry interaction over time.

The following is a summary of the Life Sciences Strategic Planning Study Committee recommendations regarding biospheric science:

- The Biospheric Research Program should participate from the biological perspective in the research outlined in "Earth System Science: A Closer View" and "Global Change in the

FIGURE 11
BIOSPHERIC RESEARCH PROGRAM



Geosphere-Biosphere" (see Section VII, Reference VII, Reference Documents).

G. CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEM

Development of a regenerative life support system with enhanced efficiency for food production and waste re-cycling involves two major basic and integrated functions—physical/chemical life support elements, and biological life support elements in a system that is known as a Controlled Ecological Life Support System (CELSS). The Division is responsible for mission operational system requirements for both physical/chemical life support systems and for technology development for CELSS. The Office of Aeronautics and Space Technology (OAST) is responsible for advanced technology development of physical/chemical life support elements and also supports some CELSS technology development.

The CELSS Program was initiated on the premise that NASA's goals would eventually include extended-duration missions with sizeable crews requiring capabilities beyond the ability of conventional life support technology. Currently, as mission duration and crew size increase, the mass and volume required for consumable life support supplies also increases linearly. Under these circumstances, the logistics arrangements and associated costs for life support resupply will adversely affect the ability of NASA to conduct long-duration missions. A solution to the problem is to develop technology for the recycling of life support supplies from wastes. The CELSS concept is based upon the integration of biological and physico-chemical processes to construct a system that will produce food, potable water, and a breathable atmosphere from metabolic and other wastes, in a stable and reliable manner. A central feature of a CELSS is the use of green plant photosynthesis to produce food, with the resulting production of oxygen and potable water, and the removal of carbon dioxide. Essential in CELSS development are investigations and technology development in the areas of plant growth, food processing, energy balance, waste processing, sensing, controls, and automated systems. It must also be determined whether full size plants can grow productively in microgravity.

The CELSS Program has integrated relationships with other Life Sciences Programs. CELSS relies on

the Biomedical Research Program to provide space human factors and environmental requirements. The Space Biology Program provides knowledge on general mechanisms of higher and lower plant development and responses to combined stresses. The Exobiology Program will aid in the identification of indigenous extraterrestrial materials for use in CELSS. And, the Biospheric Research Program provides input to small-scale modeling of biological and physio-chemical interactions and understanding Earth as a closed system.

A proposed new program initiative in response to the Life Sciences strategies in 1990-1992 is:

- CELSS Flight Projects, a collection of research activities, is underway and planned for Space Station Freedom. All are steps in the process to develop a complete or partial bioregenerative life support system for future exploration missions. The demonstration-of-technology project, "FEAST," can also be modified and adapted to provide one salad per person per day for Space Station Freedom crewmembers. (CELSS FEAST is an element of SBI.)

In addition, the following pre-Phase A and Phase A/B studies are planned to be initiated in the 1990-1996 time frame:

- CELSS Ground-based Project. As the next sequential step, advancing from the current CELSS Breadboard Facility in operation at KSC, pre-Phase A activities for a CELSS Man-Rated Test Prototype Facility.
- CELSS Flight Projects, a further set of CELSS research activities, another in a sequential series, is planned for Space Station Freedom. A science research project, "CROPS," will utilize an augmented "FEAST" to determine plant productivity in space. It is further envisioned that pre-Phase A and Phase A/B activities will begin in the late 1990's, building from previous CELSS projects, for "VAGABOND" if "CROPS" data proves that artificial gravity is needed to grow plants in space, to determine the role of gravity in increasing plant productivity. Current planning for "VAGABOND" anticipates that, due to the large volume needed, it will be a component of the Variable Gravity Centrifuge (described in Section II.D., Space Biology). The final step in demonstration of a operational CELSS system in microgravity or variable gravity

will be project "EDENS" which will test and evaluate the physical/chemical and biological technologies required for Space Station Freedom Phase 2 implementation and/or future exploration missions.

See Figure 12 for CELSS Program schedule.

The following is a summary of the Life Sciences Strategic Planning Study Committee recommendations regarding CELSS science:

- NASA should plan to develop a fully workable ground-based CELSS within a decade that will provide the basis for designing a flight module that will be integrated into space-based designs.
- NASA should continue to pursue every opportunity to fly CELSS experiments.
- Testing with two or more persons in a fully developed CELSS should occur prior to the turn of the century if NASA expects to establish the design criteria to build a spaceworthy module.

— The tests should be long enough to verify crop-biomass production, waste management, system control and monitoring, and continuous, reliable operation of all systems.

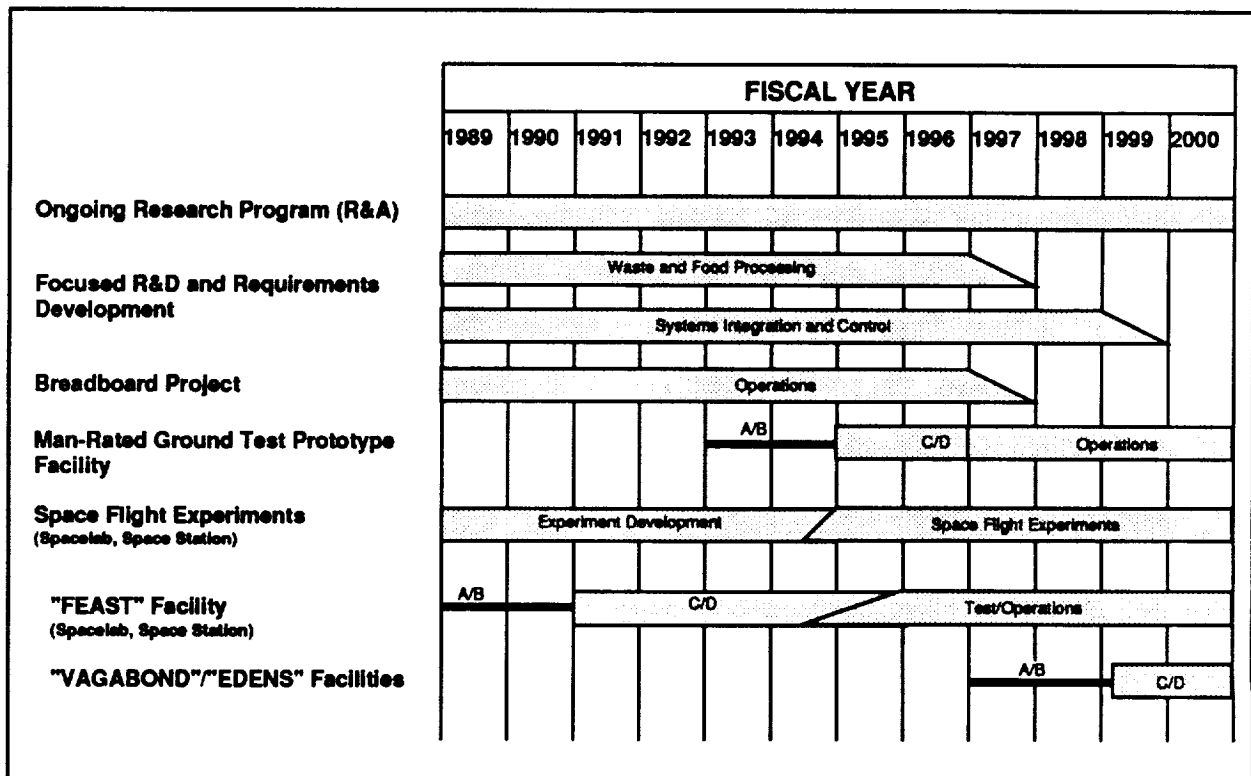
— The CELSS Program should be ready to begin development of flight-certified hardware for testing on the Space Station at about the end of the first definition phase of a lunar base or Mars mission.

H. FLIGHT PROGRAMS AND ADVANCED TECHNOLOGY DEVELOPMENT

Flight Programs

Carefully planned and executed experiments in space provide the detailed knowledge required by each of the above science programs in order to validate hypotheses and further refine ground-based research activities. Accordingly, Flight Programs is one of the two major budgetary components of the overall Life Sciences Program. Flight Programs involves the development of facilities, procedures, and hardware

FIGURE 12
CELSS PROGRAM



for that portion of life sciences research conducted in space, including scientific instrumentation, supporting equipment, mission planning, flight plan implementation, and scientific data processing. To ensure the availability of appropriate flight opportunities and experimental conditions, a variety of manned and unmanned flight vehicles and missions are utilized. These include dedicated Life Sciences missions and missions where it is possible to exploit opportunities to conduct specific Life Sciences research on missions devoted primarily to other purposes. Most of the missions currently being planned utilize the Space Transportation System (STS) and Spacelab missions, and the Space Station Freedom. International missions utilizing both United States and foreign satellites are an important part of the Life Sciences Program, and the Life Sciences Division also serves to facilitate and integrate flight research sponsored by other United States Government agencies.

The Flight Program is implemented through two major elements: *Human Space Flight and Systems Engineering* and *Space Biological Systems*. The first element contains programs and projects that support operational medicine and biomedical research requirements by developing and validating technologies through flight experiments and demonstrations involving health maintenance; specific countermeasures to physiological deconditioning; and life support systems. The second element contains the development of facilities, instrumentation, and biosensors required to conduct scientific basic and applied experiments in the areas of space biology, biospherics, and exobiology.

Advanced Technology Development Program

The Advanced Technology Development Program supports research leading to the development of advanced flight instrumentation concepts and laboratory breadboards for future Life Sciences flight experiments where accurate, comprehensive, and sensitive instruments and highly specialized devices are required. This includes effective methods and instruments for precise and accurate measurements and imaging of biological and physiological changes due to microgravity and other space flight conditions. Also involved is the development of effective technologies for environmental monitoring and control of spacecraft atmosphere and water systems and radiation dosimetry to ensure crew health, safety, and welfare, and the development of advanced flight and ground-based data processing systems and techniques.

As part of its basic complement, Space Station Freedom will include a Health Maintenance Facility (HMF) for operational medicine and advanced medical care studies. The operational requirements and technology for the HMF were developed by the Life Sciences Division and provided to the Office of Space Station. Life Sciences will maintain a watch for new technology development that might be applicable, and when the HMF is developed, Life Sciences will verify that the requirements have been met.

I. SUMMARY OF CURRENT AND PLANNED INITIATIVES

In the previous Sections (B-G) the Operational Medicine, Biomedical Research, Space Biology, Exobiology, Biospheric Research, and CELSS Programs, were described and a number of current and planned new program initiatives needed to implement the Life Sciences strategies in the near-term and the mid-/long-term were presented. Figures 13 and 14 show the scheduled new starts (Phase C/D) and planned new start decisions, with their relationships to the science programs, for these initiatives.

J. LIFE SCIENCES EDUCATIONAL PROGRAM

The educational program is an important element in developing Life Sciences activities of the near future. The Life Sciences Division plans to enhance this program by incorporating additional and expanded educational opportunities. This will be accomplished through the design and implementation of a basic set of programs that address a spectrum of educational levels. The key components of the Educational Program are primary and secondary school educational packages; university life sciences curriculum development; and conference and workshop planning for the scientific community; and continuation of the following programs:

- Undergraduate-level Space Life Sciences Training Program
- Graduate Student Research Program
- Disciplinary Research and Intern Programs in Space Biology and Planetary Biology
- Post-doctoral level Resident Research Associate Program
- Aerospace Medical Residency Training Program

FIGURE 13
LSD SCIENCE PROGRAMS RELATIONSHIP TO PROGRAM INITIATION—
NEAR TERM

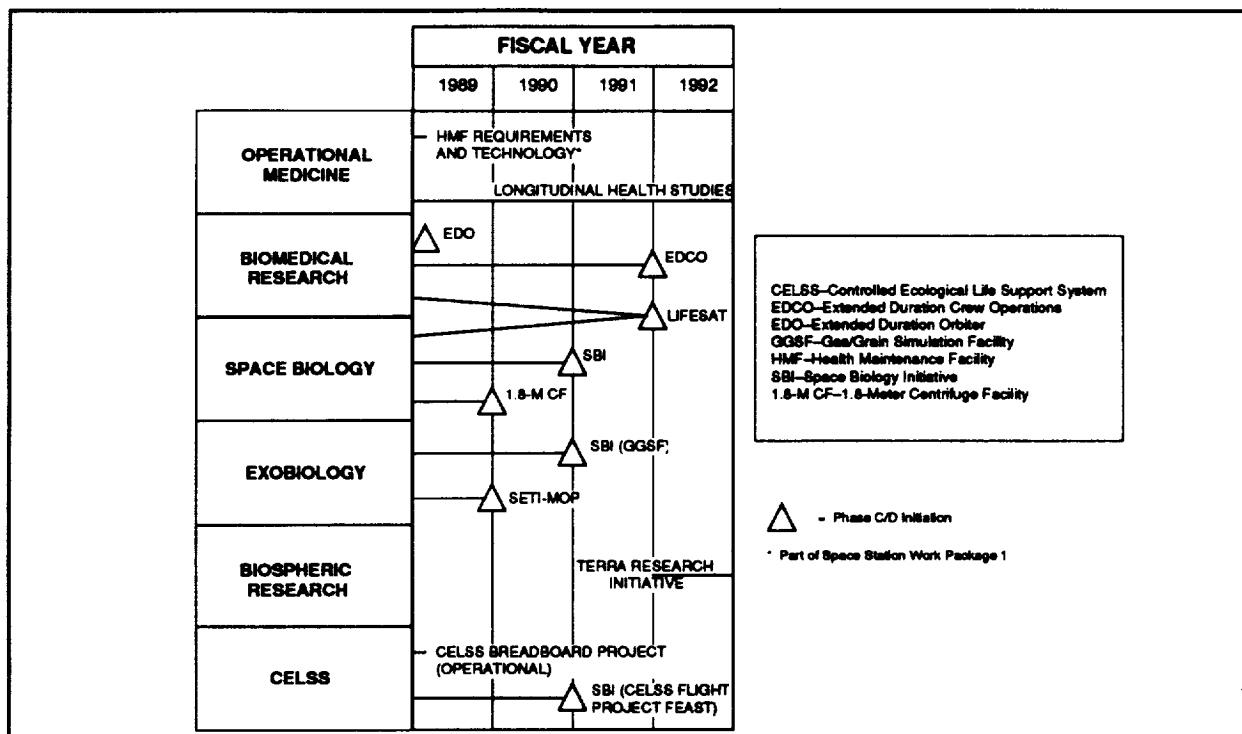
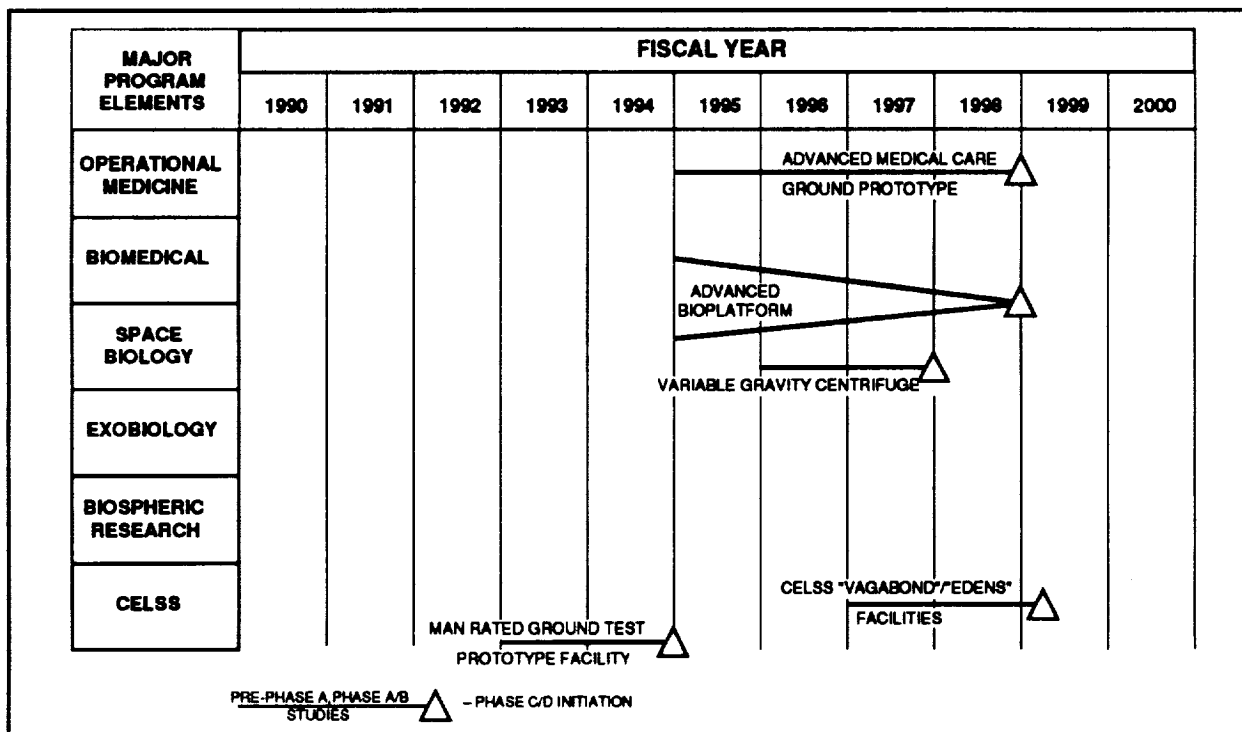


FIGURE 14
LIFE SCIENCES INITIATIVES BEING PLANNED—MID/LONG TERM



The NASA Specialized Centers of Research (NSCOR) Program, with its associated NASA professorships and training programs, will contribute to the development of a future space life scientists cadre.

K. EARTH BENEFITS FROM SPACE LIFE SCIENCES

In addition to the continuing expansion of the scientific knowledge base, space biomedical research and the technology developed as a result of this research find application to health care on Earth, such as: prevention of cardiovascular, bone and muscle disease; physiological and mathematical modeling; telemedicine; therapeutic modalities; rehabilitative medicine; radiobiology; and agriculture. Focused activities to identify and transfer such applications to the private sector are continuously pursued.

III. PROGRAM IMPLEMENTATION

This Section covers the Life Sciences strategic program implementation, including: an identification of major programmatic constraints; programmatic priorities in the near-, mid-, and long-term and budget priorities; NASA infrastructure; universities; other Federal agencies; international programs; and, access to flight.

A. MAJOR PROGRAMMATIC CONSTRAINTS

Major constraints to the successful implementation of the Life Sciences Program exist in four areas:

- Manpower
- Facilities
- New technologies
- Life sciences data base

Staffing increases, civil service and contractor, will be required, especially at the Field Centers.

Several ground and flight facilities are critical to the successful accomplishment of Life Sciences goals and objectives. In addition to existing facilities or those currently under development, new facilities envisioned are noted in section III.B below.

State-of-the-art technologies for ground and flight research and operational support must be developed, such as those critical to the provision of advanced health maintenance care, minimally invasive biomedical analytical capabilities, and biological radiation dosimetry, etc.

Another key element in future program development is the development and utilization of a national and international Life Sciences data base. The goal is to ensure proper experimental protocols and foster vigorous interpretation and analysis of all available space-flight and ground-analog data related to the space life sciences.

B. PROGRAM PRIORITIES AND DECISION PROCESS

To ensure fulfillment of its roles and responsibilities, the Life Sciences Division has established the following programmatic and budgetary guidelines for executing its programs.

From a programmatic standpoint the priorities are to:

- Maintain a research, development, and medical operations base to support manned missions, and establish mission requirements and develop enabling technologies to assure health, safety, and productivity of humans in space.
- Maintain a core research program in basic biological sciences to create opportunities to expand fundamental knowledge across the disciplines.

The Life Sciences Division goals and objectives will be achieved through the utilization of ground and flight facilities. While field center and university laboratories will be used throughout, the flight facilities to be used are:

Near-Term (1989-1992)

- STS/Spacelabs
- Exobiology instruments for specific exploration missions, such as Cassini

Mid-Term (1992-2000)

- STS/Spacelabs
- Space Station Freedom Phase I Facilities
- Small Reusable Satellites (e.g., LifeSat)
- Exobiology flight experiments (e.g., Space Infrared Telescope Facility, Mars Rover/Sample Return, Cosmic Dust Collection Facility)
- Biospherics investigations using data from Earth sciences missions

Long-Term (2000 and Beyond)

- Space Station Freedom Phase II, augmented for use as a test bed for technology development for human exploration missions
- Exobiology flight experiments (e.g., Comet Nucleus Sample Return, Mars missions)
- Evolutionary Advanced Bioplatforms

From a budget standpoint, the priorities are to:

1. Maintain the core research and development program for:
 - a. Near-term approved flight facilities and experiments (those in design and development, Phases C/D);

- b. Research and engineering infrastructure at the Field Centers; and,
 - c. Viable university and industrial base. This base will be supplemented, as resources permit, by enhanced university participation through the NASA Specialized Centers of Research (N-SCOR) program, and through augmented educational programs.
2. Maintain the appropriate flight facilities through Phase B.
 3. Maintain approved ground-based projects (those in design, development, and operations, Phases C/D/E).
 4. Maintain the necessary advanced planning studies through pre-Phase A and Phase A.

C. NASA INFRASTRUCTURE

Life Sciences Program

The first six program elements (Operational Medicine, Biomedical Research, Space Biology, Exobiology, Biospherics, and CELSS) are supported by several focused science disciplines. The Division is refining science program plans and building a data base of its discipline science needs and the requirements identified by the Life Sciences Strategic Planning Study Committee. Discipline Working Groups (DWGs) composed of scientists familiar with the goals and technology, objectives, and operations of Life Sciences Program are involved in defining the science research needs. In addition, DWGs will be critical links between NASA and the outside research community. The Life Sciences Division is planning to strengthen NASA's in-house science base through the development of strong intramural research teams. Each team will have a specific focused objective or theme of high relevance to NASA and will concentrate on multidisciplinary long-term research, including ground and flight activities.

Life Sciences Division Involvement with Program Offices

The NASA Offices of Space Flight, Space Station, and Exploration are responsible for the planning and management of the STS program, Space Station Freedom program, and future exploration missions, respectively. The Life Sciences Division has medical

operations and life support programmatic responsibilities in the STS and Space Station programs, in addition to being a major user for life sciences research. Similarly, the Division is actively involved in planning for future exploration missions and is responsible for providing life sciences and life support mission requirements and enabling technologies. Figures 15, 16, and 17 depict the Life Sciences Division responsibilities and role as a user on these programs. These programmatic responsibilities are integrated into Life Sciences' program planning and implementation.

Advisory System

The Life Sciences advisory infrastructure is an extremely important tool for program assessment and long-range planning; it encompasses both internal and external committees. The Life Sciences Program will continue to receive advice from National Academy of Sciences committees focusing on life sciences disciplines. The NASA internal advisory infrastructure includes two committees—the Aerospace Medicine Advisory Committee (AMAC) in the area of clinical and preclinical medical studies necessary to enable human space flight, and the Space Science and Applications Advisory Committee (SSAAC) primarily in the area of non-medical basic science studies.

D. UNIVERSITIES

The Life Sciences Program is planning for NASA Specialized Centers of Research (N-SCORs). N-SCORs are designated universities that possess the appropriate laboratory facilities and have the breadth of scientific expertise to conduct a broad spectrum of basic and applied research. The N-SCOR Program is viewed as critical in expanding and synergizing extramural Life Sciences research activities. Up to 10 N-SCORs will be established during 1990-1994. Integral to this program will be training programs for life scientists.

E. OTHER FEDERAL AGENCIES

Joint activities with other Government agencies are essential to the continued development of a national life sciences program base. An Interagency Working Group (IAWG) in biomedical research will consolidate and enhance joint efforts between NASA and the National Institutes of Health (NIH). Complementary ground-based research programs are being developed in the cardiopulmonary,

musculoskeletal, neuroscience, and radiobiology disciplines. A similar cooperative program is planned with the Department of Defense. Relationships with other agencies are also being developed. These joint activities will ensure that ground-based and flight facilities and the management and scientific infrastructure are available to support the needs and interests of other agencies as well as those of NASA in the utilization of space as a scientific tool.

The Life Sciences Division will coordinate across the spectrum of organizations interested in space life sciences research. Specific interests will be integrated to ensure the development and execution of ground and flight research programs that meet the needs of all participants.

F. INTERNATIONAL PROGRAM

The Life Sciences Division is continuing to pursue a vigorous international program involving the major space agencies of the world, especially in the training of life scientists. The goal of international cooperation in the life sciences is to increase the overall worldwide science return from space life sciences research. Our strategy is to shape, with our international partners, mutual goals and objectives. In so doing, we jointly minimize duplication of efforts and maximize non-duplication of technology development. To this end, NASA Life Sciences has established formal collaborative relationships with:

- Canada (NRCC)
- European Space Agency (ESA)
- France (CNES)
- Federal Republic of Germany (DLR)
- Japan (NASDA)
- U.S.S.R.

In addition, discussions have been held with several other countries.

Planning for international Joint Working Group activities on Spacelab and Shuttle is continuing, and increasing attention is being given to international space life sciences activities. Life Sciences is participating with international partners in the planning and development of Spacelab International Microgravity Laboratory (IML) missions. SL-J is a Japanese Spacelab mission and the SL-D is a series of dedicated West German Spacelab missions in which NASA Life Sciences participates. France, through CNES, is participating in the development of the Rhesus Facility, which will be flown on IML missions,

FIGURE 15
LIFE SCIENCES DIVISION INVOLVEMENT WITH STS

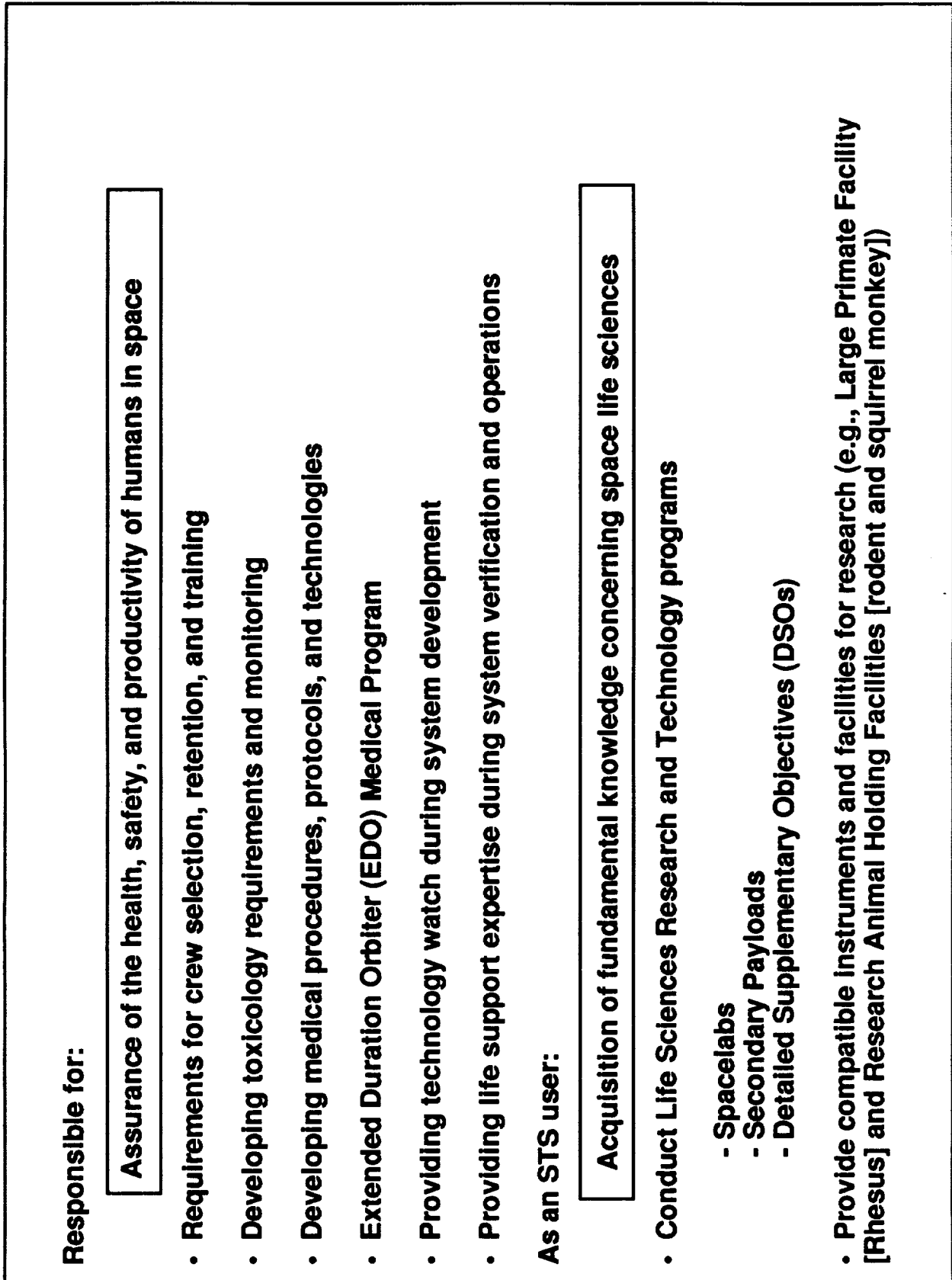


FIGURE 16
LIFE SCIENCES DIVISION INVOLVEMENT WITH SPACE STATION FREEDOM

<p>Responsible for:</p>	<p>Assurance of the health, safety, and productivity of humans in space</p> <ul style="list-style-type: none"> • Developing technology requirements for <ul style="list-style-type: none"> — Environmental Monitoring — Health Maintenance Facility (HMF) — Physiological Countermeasures • Developing medical procedures, protocols, and technologies • Developing occupational protocols • Developing procedures for operational medicine • Extended Duration Crew Operations (EDCO) Program • Providing life support and operational medicine expertise as members of Level I Space Station Control Board • Providing life support expertise during system verification <p>As a Space Station Freedom user:</p>	<p>Acquisition of fundamental knowledge concerning space life sciences</p> <ul style="list-style-type: none"> • Conduct Life Sciences Research and Technology programs • Provide compatible instruments and facilities for research (e.g., 1.8-Meter Centrifuge Facility and Space Biology Initiative [SBI] facilities and instruments)
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FIGURE 17
LIFE SCIENCES DIVISION INVOLVEMENT WITH PLANNING OF MAJOR NEW
EXPLORATION MISSIONS

Active participant in Exploration Management Group's mission planning

- Identifying critical technologies
- Developing preliminary technology development plans
- Developing and analyzing scenarios
- Providing input on crew factors
- Scientific justification for missions

Responsible for:

Acquisition of fundamental knowledge concerning space life sciences

- Maintaining ground and flight research programs to provide basis for development of enabling technologies

Assurance of the health, safety, and productivity of humans in space

- When mission is selected, providing and developing Life Support and Operational Medicine Requirements and Technologies (similar to responsibilities with STS and Space Station Freedom)

and both France and Canada are studying modules for life science experiments to be flown on LifeSat missions. Joint missions with the U.S.S.R. on the Soviet COSMOS biosatellite series will continue through 1991, and mechanisms for joint experiments and sharing of data from U.S. and U.S.S.R. manned missions are being established. In planning for the utilization of Space Station Freedom for life sciences research, international partners have committed to providing complementary inflight facilities, and integration studies are being conducted.

G. ACCESS TO FLIGHT

In the near term, a continuing STS/Spacelab series of missions will be the single most important category of flight opportunities. It is essential that ground-based life sciences research be accorded continuing and regular access to flight as a means of collecting data, validating concepts and procedures, developing countermeasures, and serving as a testbed for Space Station Freedom research and equipment. Life Sciences research will contribute substantially to the safe operation of the Space Station Freedom. Validation of hypotheses on basic biological programs in the future will require access to manned and unmanned science missions.

A strong program of STS/Spacelab based life sciences research is planned, enhanced significantly by currently planned program initiatives (Extended Duration Orbiter (EDO), 1.8-Meter Centrifuge Facility, and SBI). The initial dedicated Life Sciences mission utilizing Spacelab (SLS-1), to be flown in 1990, will be the first opportunity to collect integrated data across a broad range of correlated science disciplines since the Skylab era. The objective of SLS-1, an 8-day Space Shuttle mission, is to conduct interdisciplinary studies of human and animal biomedical responses in microgravity. Over 20 investigations will be performed on early physiological responses to weightlessness of the cardiovascular, bone, metabolic and vestibular systems. In addition, medical technology verification tests will be conducted on this mission and also on the joint U.S./Japan Spacelab mission (SL-J).

A series of Spacelab missions, some capable of extended duration operations, will be flown during the 1990's, some of these specifically in collaboration with international partners. In addition to a wide variety of manned and unmanned investigations, many of these missions will be used for the

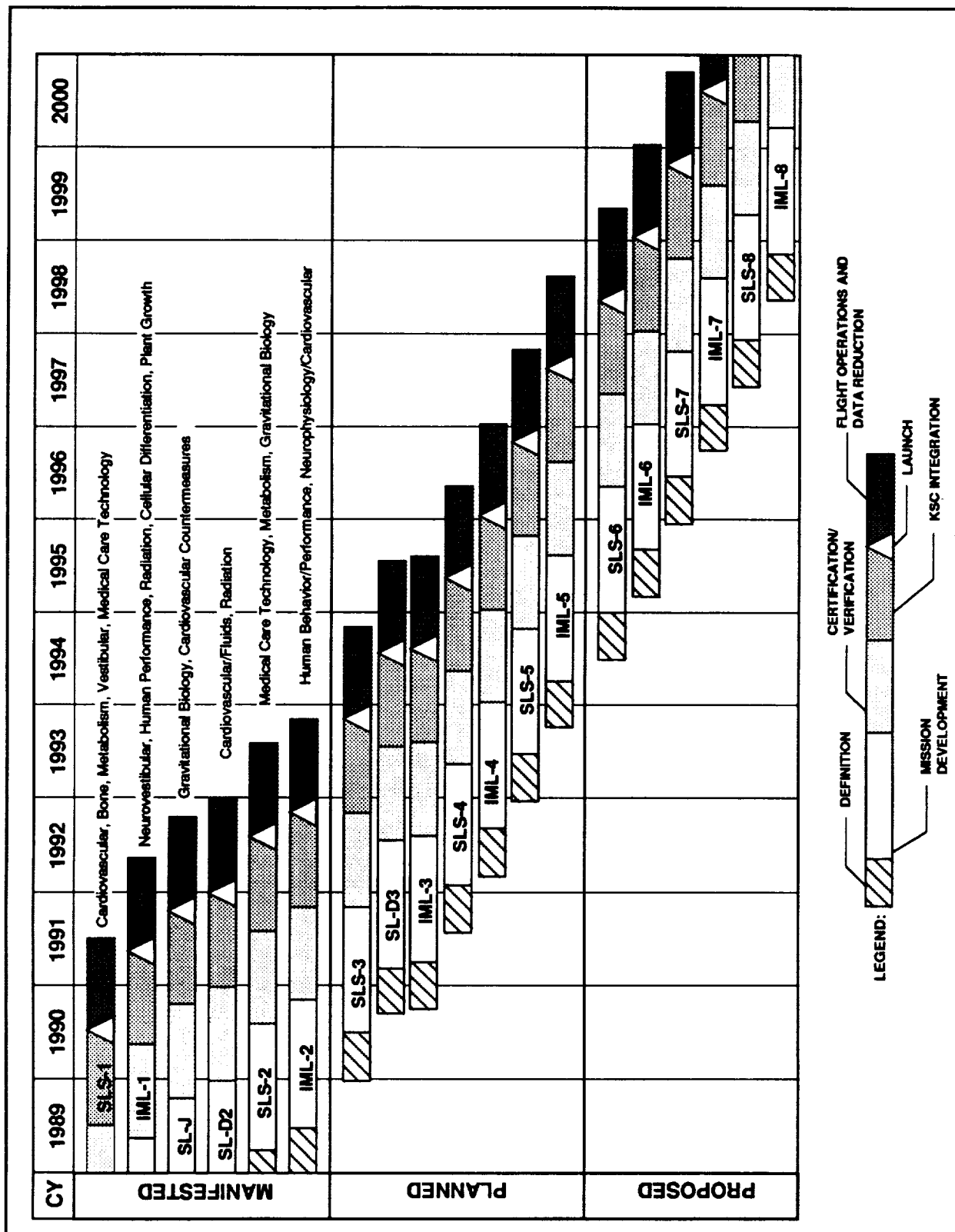
development and testing of procedures and equipment to be used on Space Station Freedom, in its initial and advanced configuration. Some SBI facilities will be flown during the SLS-3 mission and with an integrated facility package on SLS-4, along with the 1.8-Meter Centrifuge. See Figure 18 for Life Sciences Spacelab schedules.

Flight opportunities in addition to the Shuttle are necessary for Life Sciences flight research. A free-flying satellite dedicated solely to Life Sciences research will utilize an expendable launch vehicle (ELV) and an autonomous return capability. Such an autonomous system will offer a number of capabilities unavailable with the Shuttle: a flexible, independent science-driven launch schedule; mission durations of 30 days or more; unique orbital altitudes and higher orbital inclinations, including polar orbits (of special interest in determining radiation effects); simplified and standardized hardware design; and rapid turnaround, with up to two flights per year.

Space Station Freedom has great importance for Life Sciences, both from the standpoint of basic scientific research and in enabling extended duration exploration missions. Use of on-orbit facilities will initially focus on basic biomedical research to understand the various mechanisms responsible for adaptation to weightlessness and the physiological problems encountered upon return to Earth. To meet NASA operational objectives, an extended duration crew certification program extending stay times to 180 days or longer on Space Station Freedom will include advanced physiological countermeasures, to allow for nominal operations of crews for extended periods of time. On-orbit artificial gravity centrifuges will enable controlled small animal and plant research, as well as the initiation of variable gravity studies utilizing the unique capabilities of the space environment.

The capability and flexibility to be provided by this mixed fleet of flight hardware greatly enhances the outlook for Life Sciences flight missions in the 1990's.

FIGURE 18
LIFE SCIENCES SPACELAB ACTIVITIES



IV. ENABLING HUMAN EXPLORATION MISSIONS

Agency discussions on future exploration missions will have a direct influence on Life Sciences strategic and program planning. It will be necessary to ensure that the life support capabilities needed to fulfill mission system requirements and that the required technologies are available to support the mission development and operations schedules.

Under the leadership of NASA's Office of Exploration (OEXP), a broad range of possibilities for human exploration are under study and planning. Three strategies, or alternative pathways, were chosen in 1988 for analysis, including an examination of candidate "case study" missions (see Section VII-B.3):

1. **Human Expeditions**, emphasizing a significant, visible, and successful effort to establish the first human presence on another body in the solar system. The expeditionary pathway would lead to exploration without the burden and overhead associated with lasting structures and facilities. This pathway has been explored for missions to Mars and its moons.
2. **Science Outpost**, emphasizing advancement of scientific knowledge and gaining operational experience by building and maintaining an extraterrestrial outpost as a permanent observatory. The experience gained would serve as a foundation for establishing a permanent human base on another planetary body. This pathway has been explored for a mission to the Moon.
3. **Evolutionary Expansion**, sustaining a methodical, step-by-step program to open the inner solar system for exploration, space science research, extraterrestrial resource development, and, ultimately, permanent human presence. This strategy would begin with an outpost on the Moon and progress to similar bases of operations on Mars and its moons.

Any of the projected new initiatives, if undertaken, would have significant implementation impacts on the Life Sciences Division's programs. However, those involving direct expeditions to Mars would require an unprecedented buildup of focused Life Sciences unique capabilities in the areas of human

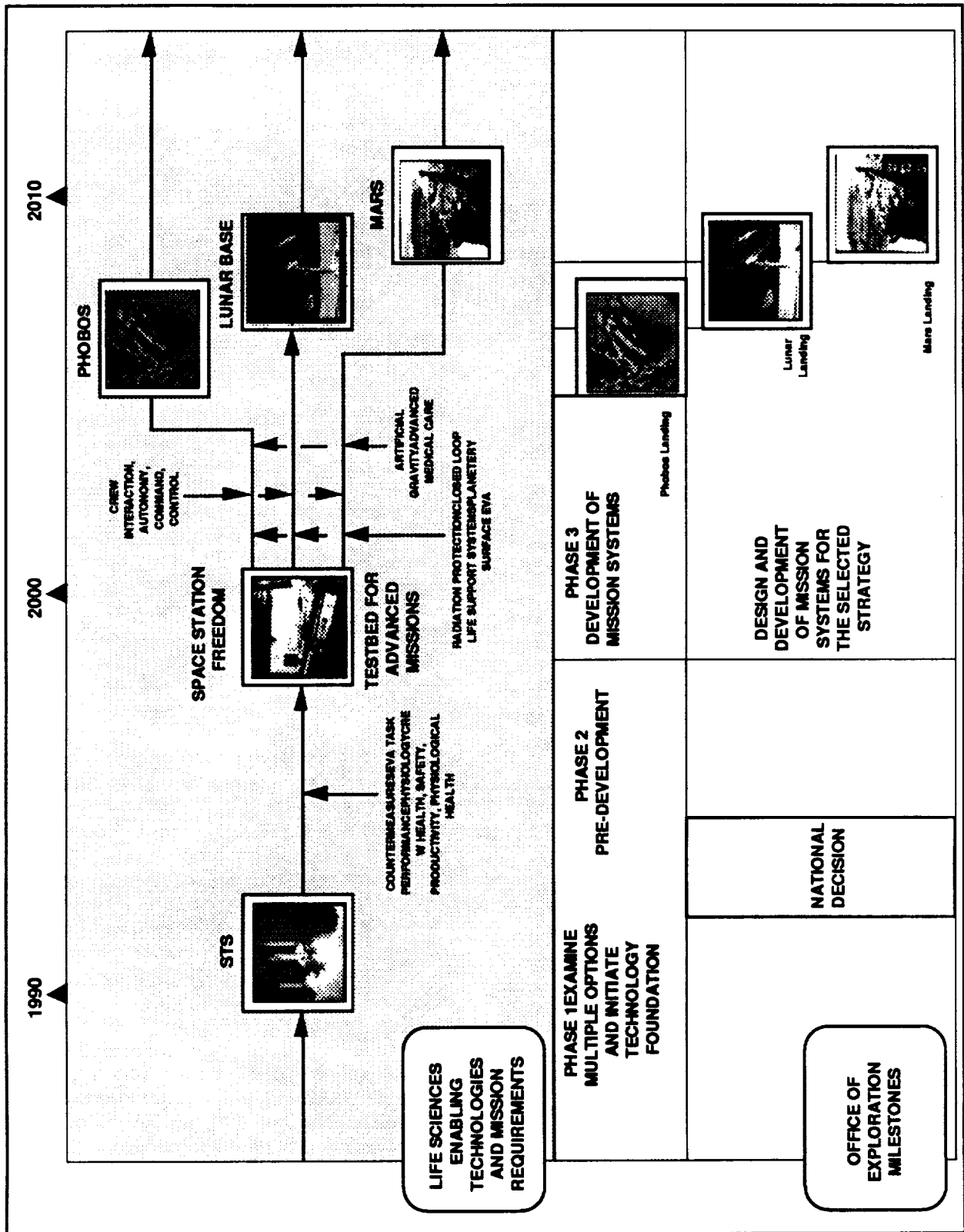
life support research and technology development, both on the ground and in space.

The Life Sciences Division is coordinating with OEXP and the Office of Aeronautics and Space Technology (OAST) on life sciences and life support mission needs.

Figure 19 shows life sciences requirements and technologies which are key elements for the human exploration scenario missions to Phobos, establishing a lunar base, and to Mars. STS and Space Station Freedom will provide the base and test beds where ground-based research activities conducted by universities and the NASA Centers will be validated. Radiation protection is required for all three scenarios. Artificial gravity as a countermeasure to physiological deconditioning is required for the long-duration missions to Phobos and Mars. An upgraded Space Station Freedom Health Maintenance Facility is needed for the lunar base and autonomous medical care capabilities are required for the Phobos and Mars missions where no rescue is possible. Bioregenerative life support systems are needed for all three scenarios. Improved EVA suits, beyond those being developed for the Space Station Freedom, are needed for planetary surface EVA. More complex countermeasures, such as artificial gravity, might be needed for Mars or Phobos missions. Better understanding of and design for crew interaction, autonomy, command, and control for all three scenarios will be required. The following is further discussion of these life sciences issues.

One of the most critical areas to be addressed in the 1990's is radiation protection. This research is essential for all exploration scenarios. The Earth's magnetic field acts as a shield against the radiation emitted from large solar particle events and from a large fraction of galactic cosmic rays. Beyond that magnetic shield radiation received is different in type, magnitude and biological effect from radiation sources in low-Earth orbits. Future missions will involve biological effects of radiation environments which are not well understood and for which prediction capabilities are limited. The ability to predict radiation effects to be encountered is crucial, as is the determination of how best to provide protection. To gain a scientific understanding and to learn how to cope with the potential physiological effects of radiation, it is necessary to acquire accurate dosimetry measurements of cosmic and solar radiation, quantify the biological effects, develop

FIGURE 19
LIFE SCIENCES STRATEGIES FOR EVOLVING REQUIREMENTS
AND TECHNOLOGIES



countermeasures, provide appropriate shielding, and develop warning systems. A baseline ground research program must be augmented by flight experiments, especially in the polar orbits to study the biological effects of HZE particles. Space flights are of particular importance, since the whole spectrum of space radiation cannot be generated at ground-based particle accelerators. The effects of galactic and solar high energy heavy ions must be studied and suitable countermeasures developed. A critical question is the evaluation of the carcinogenic potential of heavy ions so that the risk of cancer from these ions can be fully stated. Further understanding of the ability of heavy ions to induce cataracts is also required.

Currently, there is insufficient information to determine to what extent artificial gravity is required for Phobos and Mars missions. This is a physiological and technological question of great import as we move forward into the next century. In the early 1990's, we will be studying the physiological and technical requirements for such facilities.

The Health Maintenance Facility presently under development for Space Station Freedom (SSF), with some upgrades, should suffice for a science outpost on the moon and the lunar portion of evolutionary expansion missions. Both scenarios will include a capability for quick rescue and return to Earth. However, medical self sufficiency will be necessary for expeditions to Phobos or Mars or expanded evolutionary missions, where no rescue is possible.

Adequate life support systems must be developed to provide and monitor the basic human needs of air, food, and water on evolutionary expansion missions to Phobos or Mars.

The currently available technology for life support systems should be adequate for the initial operations of SSF. However, the long-term objective should be to minimize resupply requirements by closure of as many loops as possible. Continued research and development of physical-chemical, as well as bioregenerative systems is necessary to provide the technology base for exploration and evolutionary expansion missions. The logistical cost of atmosphere, food, and water resupply makes the development of an efficient system for reclamation and recycling an urgent need.

Improved EVA suit capabilities under development for SSF, which include more durable materials, helmet

mounted displays, improved mobility and dexterity, and higher internal pressures, must be reassessed and enhanced for exploration and expansion missions. Project Pathfinder EVA activities are essential to developing new technologies for such systems.

Humans exposed to extended duration missions must be able to function productively and safely, and adapt rapidly to the new environments to which they will be exposed. This general area, called Humans-In-Space, is critical to missions success. Humans-In-Space includes such areas as crew selection, training, interaction, as well as the "man machine" interface. Long-term isolation and confinement in hostile environments makes such research critical. Studies with analogs such as underwater environments and polar bases, along with both U.S.S.R. and U.S. space experience has given some insight to the importance of habitability to performance, productivity, and safety of operations. This includes both physiological and psychological aspects of habitability.

Maintaining physiological equilibrium is directly related to the life support systems, as well as overall vehicle environmental factors including noise, lighting, color, and temperature. Psychological well-being is related to factors such as isolation, crew compatibility, and a balance between work and recreation. The overall objective must be to optimize performance, productivity, and safety of operations. A critical concern in this regard is the determination of appropriate activities for humans versus those that are better handled by machines, while minimizing boredom and occupational risks.

In 1987, Project Pacer was proposed to address all Life Sciences elements needed for future human exploration missions. The decision was made to include certain of those elements in the Humans-in-Space component of Project Pathfinder, which is managed by OAST. Life Sciences was directed to propose its remaining elements through separate initiatives. Included in Project Pathfinder are the requirements definitions for food technology development to support Controlled Ecological Life Support System (CELSS), and for human factors, environmental factors, and extravehicular activity. Also included is research into human capabilities and limitations for physical and cognitive activities. Focus will be maintained upon technologies capable of accommodating human physiological requirements and adaptive changes during long-

term confinement, exposure to unnatural gravity, and unaccustomed risk and stress. Understanding of needs for artificial gravity and radiation protection and how best to meet those needs are key components of Humans-in-Space.

The interlocking relationships among the Space Shuttle (STS), Space Station Freedom, and the major human exploration missions under consideration is illustrated in Figure 20. The Space Station will serve as the major test bed for advanced missions, whether those missions are to proceed through a Lunar Base to a Mars mission or directly to Mars. From a Life Sciences and Life Support standpoint, Lunar Base research will focus on radiation protection, artificial gravity, food systems, regenerative life support, crew interactions, and advanced medical care. These critical areas of research will be addressed intensively on Space Station before the lunar and Mars missions.

By the late 1990's, extensive flight and ground-based clinical and biological research experience will have been accrued utilizing Space Station and the continuing series of STS, Spacelab, and biopatform flight missions. These activities will be planned and coordinated to ensure that answers are available when needed to allow appropriate and timely design, operational and programmatic decisions to be made enabling the exploration missions of the 21st century.

V. MANAGEMENT

To fulfill the responsibilities and exploit the opportunities within the NASA Life Sciences Program there must exist clearly enunciated objectives and plans, a solid management structure and process, adequate programmatic and institutional resources, and internal and external advice and support. The Life Sciences Division organization is shown in Figure 21.

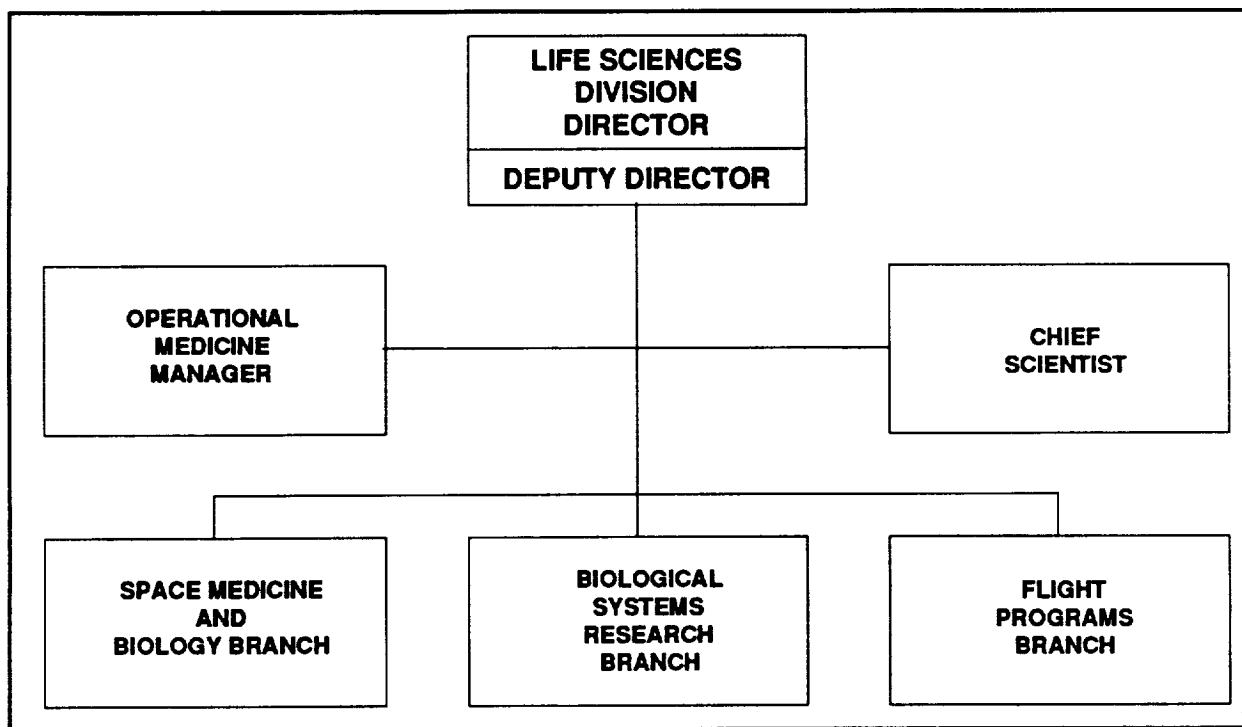
The Life Sciences Division will continue to concentrate upon development of an infrastructure to facilitate the future program growth envisioned to support major exploration programs of the 21st century. The basic structure is in place and will be enhanced by upgrading Field Center facilities and capabilities, enriching cooperative programs with other other Federal agencies, strengthening ties to the university and industrial communities, and increasing international collaboration.

NASA Field Centers are the source of expertise for program definition; research program implementation; unique ground and flight facility acquisitions; and, flight mission planning and operation. Center management is represented on the Life Sciences Senior Management Council, which ensures adequate communication and healthy working relationships.

The following summarizes the significant life sciences activities and project management conducted at the major NASA Field Centers:

- Ames Research Center—Management for: SBI (non-human activities elements); 1.8-Meter Centrifuge; Rhesus Facility; Research Animal Holding Facility; science modules for LifeSat; and, COSMOS flights. Research and development in: biomedical disciplines (with primary emphasis upon basic sciences); human factors; planetary environments and artificial gravity requirements for future human exploration missions; biospherics; exobiology; CELSS technology and flight experiments; and, advanced high pressure EVA suits.
- Jet Propulsion Laboratory—Exobiology flight experiments and SETI sky search.
- Johnson Space Center—Project management for: Operational Medicine; Space Station Freedom HMF and Exercise Countermeasure Facility;

FIGURE 21
LIFE SCIENCES DIVISION ORGANIZATION



EDO; EDCO; SBI (human research elements); LifeSat spacecraft development; Intact Cosmic Dust Collection Experiments; and Spacelab Life Sciences missions. Research and development in: biomedical research (with primary emphasis upon clinical and applied sciences and countermeasures); environmental health support for manned missions and space human factors; radiation health, environmental monitoring, and operational life support; advanced high pressure EVA suit; EVA systems requirements and training; and lunar CELSS.

- Kennedy Space Center--Full range of occupational and environmental ground support programs for STS operations. Project management for CELSS Breadboard. Research in plant physiology as a component of the Space Biology Program. Pre-launch and landing support activities for life sciences flight experiments.
- Marshall Space Flight Center--Research, development, and project management for Space Station Freedom Environmental Control and Life Support System. Management for IML missions.

A formal Life Sciences Program Requirements System has been implemented. A hierarchical set of controlling documentation for science and flight programs is key in this system and will be used as a principal management tool in the conduct of the overall LSD Program and specific programmatic elements. Special attention will be given to assuring the linkage of science needs to flight programs, with requirements traceability and timely management action as key considerations.

The Life Sciences Division Science Management Plan is incorporated herein by reference. It describes in detail the major research program elements, the relative roles and responsibilities of the Division and the implementing NASA Centers and their staffs, and sets forth implementation procedures.

Recently, the OSSA, Life Sciences Division was assigned responsibility to lead the Agency Science Working Groups of the Life Sciences/Support Management Council. This will assure horizontal integration of research and science objectives, outlined in this plan, with the life support mission requirements, technology and man systems development activities programmed and budgeted by the other Headquarters program offices.

VI. RESOURCES

Included in the space life sciences core program are those activities which are currently approved and budgeted. Figure 22 shows the relative distribution of resources for FY 1989. Figure 23 shows the relative distribution of resources for the science activities.

Past Life Sciences budgets have been relatively modest (less than \$100 million annual funding). As the pace of the United States manned space program increases due to the return-to-flight of the STS and our move into the Space Station era, both future opportunities and challenges will require substantial funding increases for Life Sciences. This includes funding for experiment developments currently underway for STS/Spacelab flights and initial definition of research to be conducted on the Space Station Freedom. Long-term human exploration will require major funding to conduct the required research and develop necessary countermeasures. This will include research to understand the role of artificial gravity on plants, animals, and humans for long periods, as well as the development of a bioregenerative life support system to provide economical sustenance in space. Figures 24, 25, and 26 show the FY 1989-1990 budgets.

FIGURE 22
LIFE SCIENCES DIVISION
CORE PROGRAM

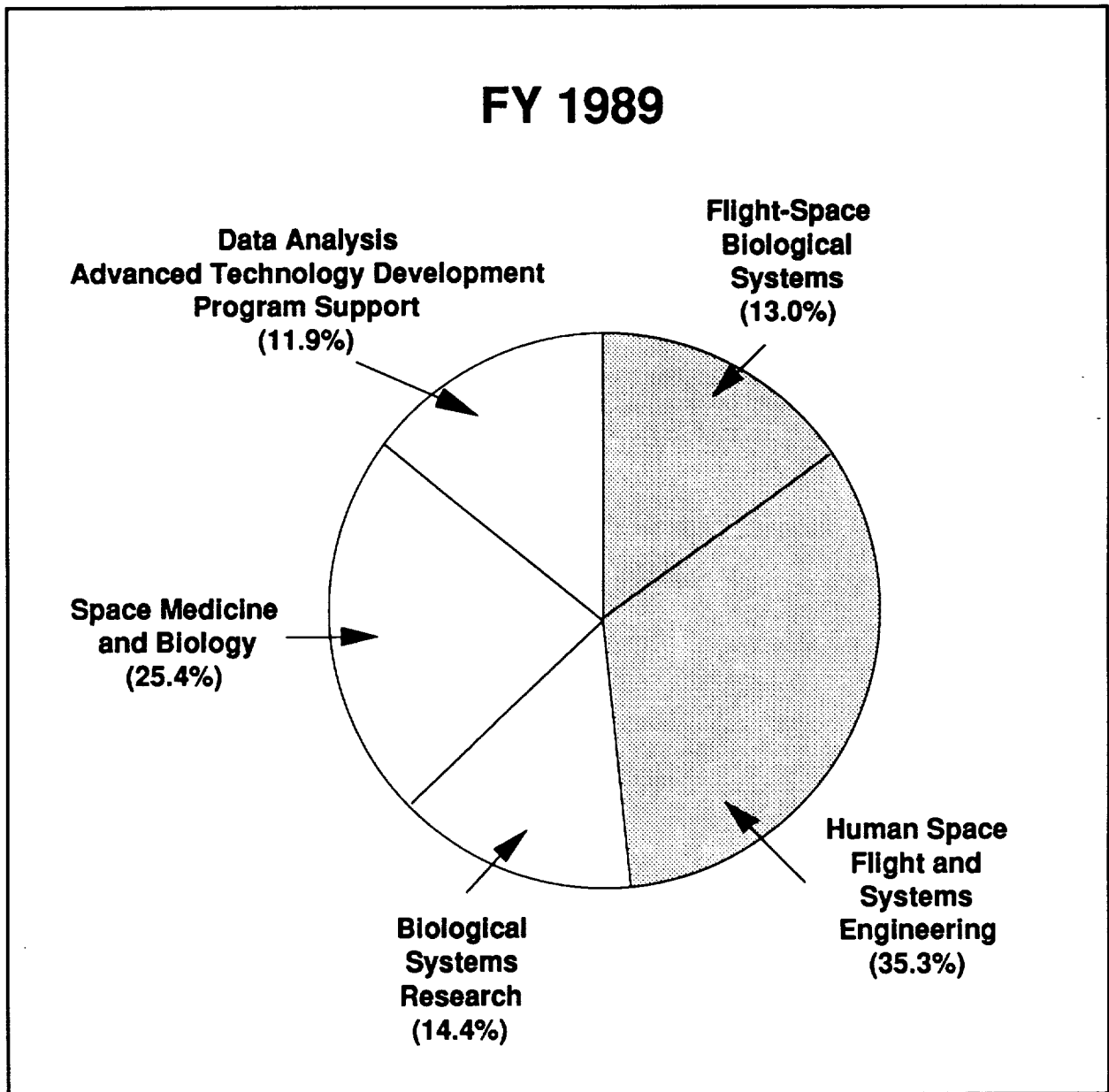


FIGURE 23
RELATIVE DISTRIBUTION OF SCIENCE ACTIVITIES
(FY 1989)

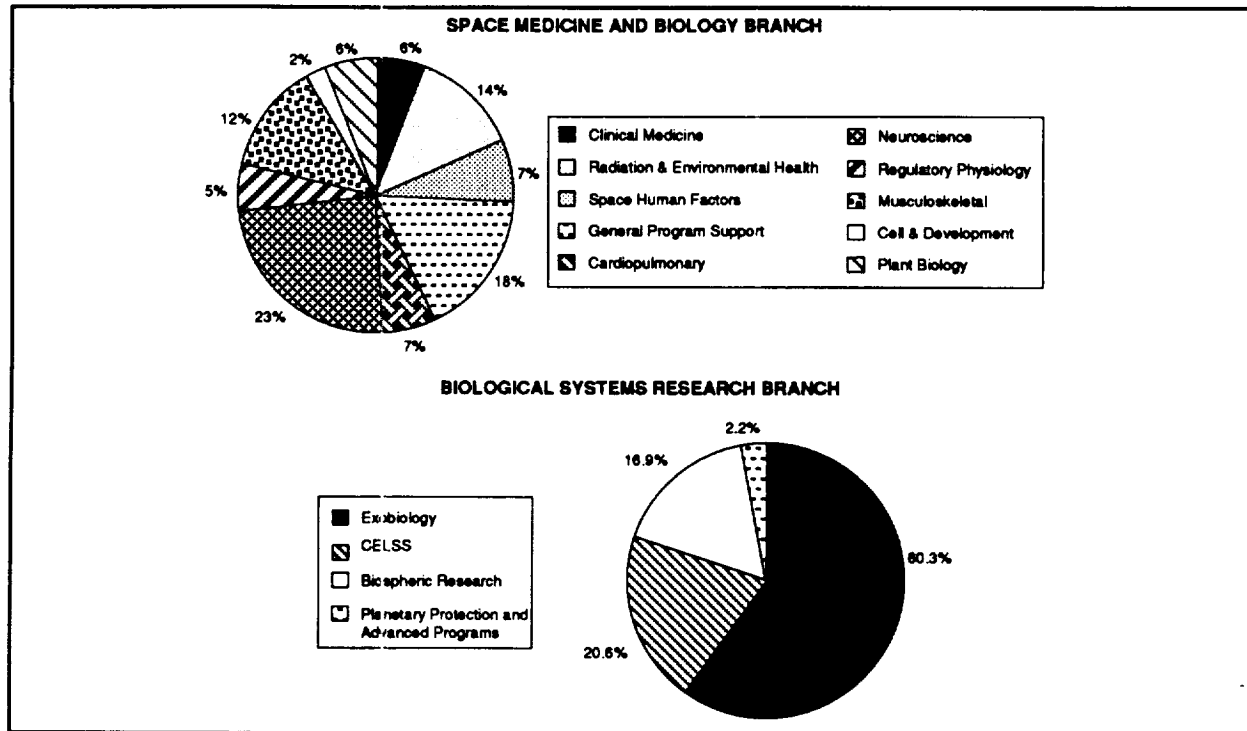
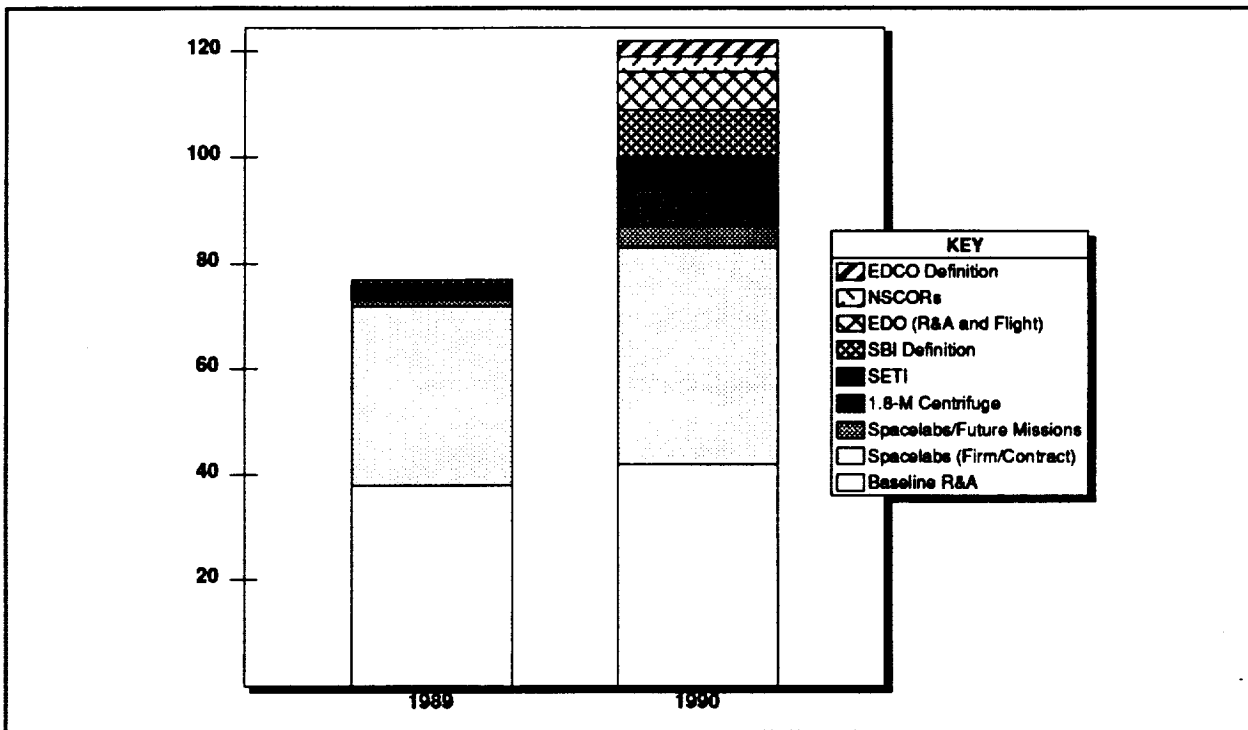


FIGURE 24
LIFE SCIENCES PORTION OF PRESIDENTS FY 1990 BUDGET

	<u>FY 1989</u>	<u>FY 1990</u>
Research and Analysis	40.4	53.8
Life Sciences Flight Experiments		
— Human Space Flight and Systems Engineering	27.6	42.8
— Space Biological Systems	10.1	27.6
TOTAL	<u>78.1</u>	<u>124.2</u>

**FIGURE 25
LIFE SCIENCES FY 1990
BUDGET INFORMATION**



**FIGURE 26
LIFE SCIENCES FY 1990
BUDGET INFORMATION**

	<u>FY 1989</u>	<u>FY 1990</u>
Baseline R&A	38.2	42.2
Spacelabs (Firm/Contract)	34.5	41.5
Spacelabs/Future Missions	.9	4.1
1.8-M Centrifuge	1.3	7.2
SETI	2.2	6.8
SBI Definition	1.0	9.0
EDO (R&A and Flight)	-	7.4
SCORs	-	3.0
EDCO Definition	-	3.0
TOTAL	78.1	124.2

VII. REFERENCE DOCUMENTS

A. *Life Sciences Division Science Management Plan*

B. Other NASA Documents

1. 1989 *Long-Range Program Plan*
2. *OSSA Strategic Plan 1988*
3. *Beyond Earth's Boundaries—Human Exploration of the Solar System in the 21st Century*, OEXP 1988 Annual Report to the Administrator
4. *NASA Leadership and America's Future in Space* (The Ride Report), 1987

C. *Pioneering the Space Frontier*, National Commission on Space, 1986

D. Advisory Reports of Particular Significance to Space Life Sciences

1. 1979 - *Life Beyond the Earth's Environment: The Biology of Living Organisms in Space* (The Bricker Report), Space Science Board, National Research Council
2. 1981 - *Origin and Evolution of Life—Implications for the Planets: A Scientific Strategy for the 1980's* (The Margulis Report), Committee on Planetary Biology and Chemical Evolution, National Research Council
3. 1988 - *Earth System Science: A Closer View* (The Bretherton Report), Earth System Sciences Committee, NASA Advisory Council
4. 1987 - *Space Technology to Meet Future Needs* (The Shea Report), Committee on Advanced Space Technology, Aeronautics and Space Engineering Board, Commission on Engineering and Technical Systems, National Research Council
5. 1987 - *A Strategy for Space Biology and Medical Science for the 1980's and 1990's* (The Goldberg Report), Committee on Space Biology and

Medicine, Space Science Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council

6. 1988 - *Space Science in the Twenty-First Century: Imperatives for the Decades 1195 to 2015 Life Sciences* (The Swisher/Usher Report), Task Group on Life Sciences, Space Science Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council
7. 1988 - *Exploring the Living Universe: A Strategy for Space Life Sciences* (The Robbins Report), Life Sciences Strategic Planning Study Committee, NASA Advisory Council
8. 1986 - *Remote Sensing of the Biosphere* (The Botkin Report), Space Science Board, National Research Council
9. 1986 - *Global Change in the Geosphere-Biosphere: Initial Priorities for an IGBP*, National Research Council, National Academy of Sciences.

E. NASA Management Instructions

1. 8900.3B, Astronaut Medical
2. 1152.59C, Medical Boards in Support of Crew Qualification
3. 8900.1B, NSTS Operational Medical Responsibilities
4. 7100.8B, Protection of Human Research Subjects
5. No. TBD (14 CFR Part 1232), Animal Use in Research

F. Interagency Memoranda of Understanding

1. NASA; USAF—Life Sciences Activities in Support of Space Transportation System
2. NASA; Defense Nuclear Agency—A Cooperative Program for the Radiobiological Protection of Humans in Space

3. NASA-KSC; Local External Medical Care Deliverers—Emergency Services in Case of Disaster/Mass Casualty
4. NASA-ARC; USAF Space Division—USAF Participation in Development Testing of an Advanced Technology Space Suit Assembly
5. NASA; National Institutes of Health—Cooperative Program in Biomedical Research

G. International Bilateral Agreements

1. NASA; ESA (European Space Agency)
2. NASA; CNES (France)
3. NASA; NASDA (Japan)
4. NASA; CSA (Canada)
5. NASA; DLR Federal Republic of Germany)
6. USA; USSR (Space Biology Working Group)

